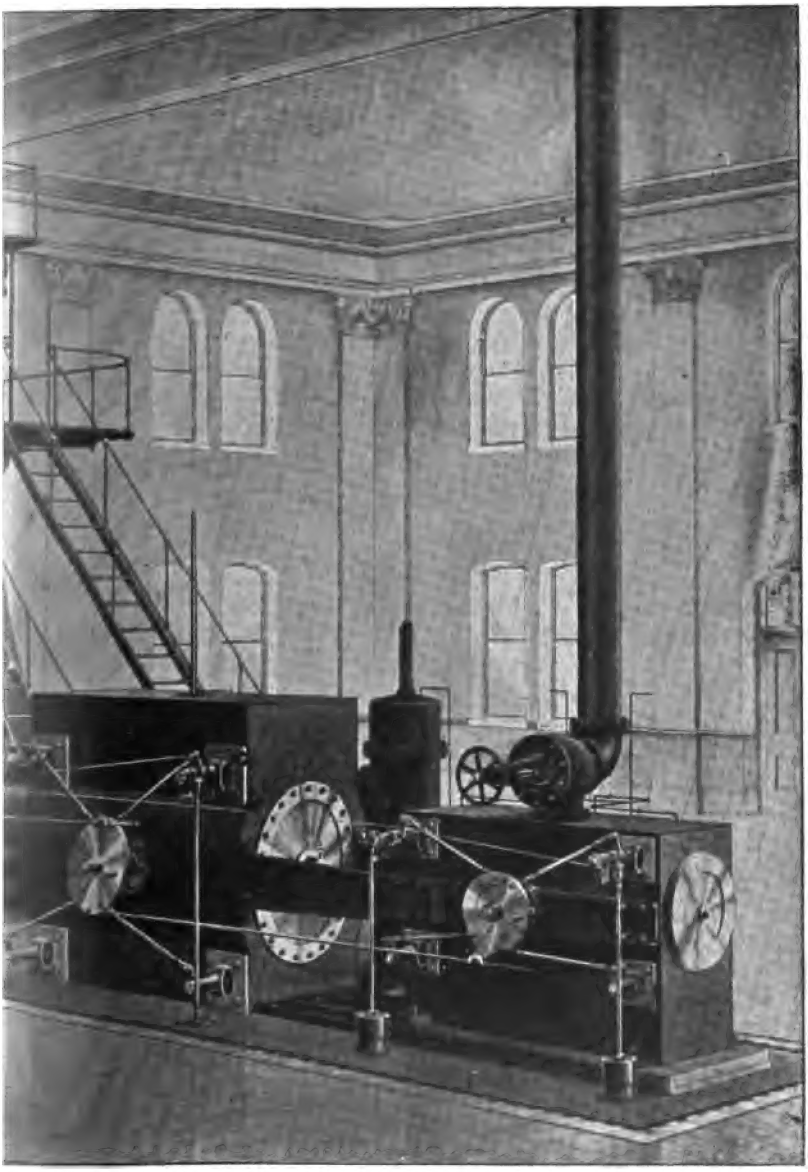
REFRIGERATING MACHINE OF THE



QUINCY MARKET COLD STORAGE CO. (Frontispiece.)

PRINCIPLES AND PRACTICE

OF

ARTIFICIAL ICE-MAKING

AND

REFRIGERATION.

COMPRISING

PRINCIPLES AND GENERAL CONSIDERATIONS: PRACTICE AS SHOWN BY PARTICULAR SYSTEMS AND APPARATUS; INSULATION OF COLD STORAGE AND ICE HOUSES, REFRIGERATORS, ETC.; USEFUL INFORMATION AND TABLES.

BY

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MEMBER OF AMERICAN SOCIETY OF REFRIGERATING ENGINEERS; ASSOCIATE MEMBER OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

THIRD EDITION, REVISED AND ENLARGED.

ILLUSTRATED BY TWO HUNDRED AND FIVE ENGRAVINGS.

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PREFACE TO THE THIRD EDITION.

THIS third edition of "Ice-making and Refrigeration" will be found to contain a large amount of new material, in addition to the greater part of the original matter used in previous editions. The scheme of sub-division into four parts has been adhered to as heretofore, although there has been some rearrangement of material. In other words, the present is unqualifiedly a revised and enlarged edition, and in view of the fact that the demand for the previous editions exceeded our anticipations, we feel justified in looking forward to a favorable reception for this present edition.

As to the quality of the material, both old and new, we will simply say that it has been our aim to bring together only such as was practical and essentially up-to-date. We candidly acknowledge the crudeness of our previous efforts, but hope that some real merit may be found in the present work. Whether or not such is the case we will leave to the judgment of others.

As to the record of the art since the previous issue, the most significant event we have to chronicle is the formation of the American Society of Refrigerating Engineers. This body has already held two annual meetings and the announcement for the third is out as we are writing. The record up to date indicates that this society has already established itself as one of the recognized engineering bodies of the day.

In closing we wish to acknowledge our gratitude for previous generous patronage, and to state that we will be equally grateful for a corresponding patronage in the present case.

LOUIS M. SCHMIDT.

LYNN, MASS.,
November 22, 1907.

PREFACE TO THE SECOND EDITION.

THE fact that the first edition of "PRINCIPLES AND PRACTICE OF ARTIFICIAL ICE-MAKING AND REFRIGERATION" has become entirely exhausted and the demand continues unabated, accounts for this new and enlarged edition.

While in the present volume, the original arrangement and division of the subject into four parts have been retained, the service of the book has been extended by the addition to each part of new and up-to-date matter, fully illustrated, by which means it is believed that full justice has been done to the subject in all its branches and details.

Since the publication of the first edition of the book, the industry of refrigeration and ice-making has become continually more firmly established. Conventions of interested parties are held periodically. A beginning has been made in the way of standardization. Some additions have been made to the bibliography of the subject, while periodical literature has maintained a vigorous existence. Altogether the prevailing feeling throughout the field indicates cheerfulness and a healthy condition.

Under such conditions, and with the record of the first edition in mind, we can feel some assurance in hoping for a favorable reception of this second edition.

LOUIS M. SCHMIDT.

LYNN, MASS.,
December 1, 1903.

PREFACE TO THE FIRST EDITION.

In the preparation of this volume the central idea has been to produce a representation of the status of the art of Mechanical Refrigeration and Ice-Making as it stands to-day.

For the proper comprehension of the subject a general knowledge of the principles involved is essential. To provide this has been the object in the preparation of Part I.

How these principles are applied in practice is brought out in Part II. by descriptions of representative apparatus as produced by some of the leading manufacturers in the field.

The subject of Structural Insulation was considered of sufficient importance to be assigned to Part III. by itself.

In Part IV. will be found tables and general information having a bearing upon the subject under consideration.

Acknowledgment of obligations is due to many who have rendered valuable assistance, including the manufacturers of the apparatus described; to an able article in the *Century Magazine*, by Mr. William Clark Peckham, on "Absolute Zero," which was of assistance in the preparation of the chapter on "Liquid Air;" and Messrs. O. R. Young, editor, and Francis H. Boyer, A. S. M. E., of the *Engineers' Magazine*, for valuable help from the department on "Refrigeration" so ably conducted by the latter.

In the matter presented it is hoped that there may be found something of value to the prospective investor, to the owner and user of refrigerating apparatus, to the operating engineer and to the student. Should our hopes show some measure of realization we will be satisfied.

LOUIS M. SCHMIDT.

LYNN, MASS.,
February 21, 1900.

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PART I.

PRINCIPLES AND GENERAL CONSIDERATION OF THE SUBJECT.

CHAPTER I.

HISTORICAL.

THAT we live in an age of progress, calls for no demonstration. New ideas are being constantly developed, and new industries are springing up tending to the uplifting of mankind. One of the greatest achievements of this remarkable age, one destined to be far-reaching in its results, is the production of practical and commercially successful machinery for the manufacture of artificial ice and for mechanical refrigeration. While the art is already well established, what has already been done is but a step in the field over which it is to be extended in the future. There is bound to be an increasing demand for its application in places where, without it, ice would be practically unknown, for transportation of perishable merchandise, both by land and sea, for cold storage warehouses, and for packing houses.

The artificial production of ice cannot be claimed as a modern achievement. Ages ago, in India, water was frozen in shallow, porous earthen dishes, resting on some non-conducting material, as straw or grass, by being exposed to currents of air during the night.

It is a comparatively old story to cool or freeze liquids by dropping saltpetre in water or mixing salt with ice or snow, the method commonly employed for freezing ice-cream and ices.

The up-to-date method of producing ice, or refrigeration, involves the operation of improved, compact and efficient apparatus by means of high-class compound or multiple expansion condensing engines.

The progress from the methods of India to those of to-day was not by any means sudden. There has been a gradual growth, and the honor for success can be attributed to no single individual. The lion's share of the credit, however, as might be expected, belongs not only to the 19th century, but particularly to the latter part of the same. A few of the names of the earlier individuals who are to be recognized in the history of the art, with a date to indicate the time of their period of activity, is all we feel permitted to present here. Among these are to be mentioned Blasius Villefranca, 1550; Latinus Tancredus, 1607; Dr. Cullen, 1755; Leslie, 1810; Vallance, 1824; Kingsford, 1825; Perkins, 1835; John Gorrie, 1850; Nesmond, 1852; Twining, 1855; F. Carré, 1860 and 1861; Tellier, 1861 and 1872; Kirk, 1861 and 1863; Pictet, 1863; O. Kropff, 1864; Windhausen, 1869; Prof. Linde, 1875.

Many names could be added to this list, especially if the attempt were made to include those who have attained prominence during the past few years.

The principles involved in the process of mechanical refrigeration are as simple as they are ingenious. The results obtained may seem incompatible with the methods pursued, as for instance, to obtain ice or to cool a room by the use of apparatus whose primary motive-power is obtained from heat. Before any of the wheels are turned, all the parts of the system may be at the normal temperature of the surroundings. Furthermore, heat flows from a warmer to a cooler body, never the reverse. How then can one part of the system be reduced in temperature below the rest? Here is where the mystery lies.

The first step towards the solution of the mystery lies in the consideration of the fact that all the bodies in the system are not in the same state or condition of matter at the normal

temperature of the surroundings found. In different parts of the system there will probably be found bodies from each of the three states or conditions, the solid, the liquid, and the gaseous. Some bodies may be made to assume each of the three states of matter without undergoing a change in their nature or chemical composition. We are all familiar with the transformation which water may be made to undergo, and the methods required to produce the results. Water, for instance, a liquid, by being heated may be changed to steam, a gas, or by being cooled, or having heat taken away, may be changed to ice, a solid. This we are all familiar with as going on under the conditions of the ordinary atmospheric pressure. We know then that the amount of heat a body contains has a bearing on the fact as to whether it is a solid, a liquid or gas. It is also a fact that the pressure to which a body is subjected tends to influence the state in which a body is found. An increase in pressure tends to reduce a body from a gaseous to a liquid or a solid state. An increase in the pressure acts contrary to an increase in the temperature or in the heat which a body contains. Accordingly some bodies that at normal temperature and atmospheric pressure are gaseous, may be reduced to a liquid by an increase in pressure. Furthermore, with the pressure unchanged, a body to pass from the liquid to the gaseous state must receive heat.

Let us consider for a moment the conditions involved in the method referred to, of obtaining ice so long ago in India. It may be readily surmised that evaporation had considerable to do with the results obtained. In fact, it had all to do with it. The currents of air assisted the evaporation, by carrying off the water vapor that was formed. Heat was needed to change to vapor whatever water was evaporated. This heat was of course given up principally by water remaining in the containing vessel. Thus the water was cooled, and if the process was continued sufficiently, a thin layer of ice could be obtained on the surface.

We shall see that the principles involved in the modern methods are much the same as outlined above. The process

has simply been condensed and brought into compact form and under control.

The elementary principles of the subject are included under the titles METHODS OF GENERATION and METHODS OF APPLICATION, while the *raison d'etre* is found in the APPLICATIONS, of which one of the most important is ICE-MAKING.

The systems of generation that have survived, and that may be regarded as commercially successful, are respectively, the absorption system and the compression system.

Under the absorption system, the method employing ammonia is the only one to be considered. Under the compression system may be included the ammonia compression system, the sulphur di-oxide system, the carbonic anhydride system, and the compressed air system.

Methods of application are classified as direct and indirect. In the direct method the refrigeration of the pipes conveying the refrigerant are located at the place where the refrigeration is desired. In the indirect method the refrigeration is effected by means of a secondary medium, which has previously been reduced in temperature by the action of the primary refrigerating medium.

There are two distinct classes of the indirect method, respectively employing brine and air as the secondary medium.

Ice-making is a special application of particular importance of the indirect brine system.

STATISTICS.

For the benefit of those who delight in statistics we give herewith a few selected from an extended compilation by Mr. E. H. Balzhiser.

Consumption of natural ice in New York Zone:

From 1880 to 1890, 1,500,000 tons per annum.

Present rate (1906), 300,000 tons per annum.

Average production in Hudson River and Maine Zones:

1890–1899, 4,135,000 tons per annum.

1900–1905, 3,613,000 tons per annum.

The difference plus the increase in consumption is taken care of by machine production.

DATA FOR UNITED STATES.

Record for Year 1899.

	Natural.	Machine.	Total.
Ice production—tons	21,000,000	8,000,000	29,000,000
Wastage—estimated	35 per cent.	5 per cent.	
Consumption			21,250,000
Estimated population			75,000,000

Consumption per capita, 566⅔ lbs.

RELATIVE DATA FOR DIFFERENT SECIIONS OF COUNTRY.

	Southern States.	Northern States.	Rocky M. States and Ter.	U. S.
Production of Machine Ice for 1905.....	36.4 %	57.3 %	6.3 %	100 %
Proportion of Machinery used for Ice ..	75 "	27 "		43 "
Total capacity of Plants—tons per day..				72,000

Capacity for U. S. possessions and for Canada, each about 1500 tons per day.

VALUE OF MACHINE ICE.

Year.	Wholesale value per ton on platform. Southern Zone.	U. S.
1870	$15.00	—
1880	7.50	—
1890	5.00	3.09
1900	3.74	—
1905	—	2.13

COST OF ICE IN U. S.

Year.	Kind.	Cost per ton. Production on platform.	Delivery.	Total.
1889,	Natural	$1.75	$1.90	$3.65
1905,	Natural and Machine....	1.61	2.12	3.73

Increased cost of delivery is attributed to the extension of cities and the effect of introduction of refrigerating machinery.

RELATIVE CONSUMPTION OF NATURAL AND MACHINE ICE FOR CINCINNATI.

Year.	Per cent. Natural.	Per cent. Machine.
1889.	76 per cent.	24 per cent.
1905.	10 "	90 "

GROWTH OF MANUFACTURED ICE INDUSTRY.

Year.	Average Value per Plant. Capital Invested.	Product.
1880	$35,749	$15,565
1890	44,353	22,077
1900	48,544	17,630

Falling off in value of product is attributed to extension of industry northward. The reduction in price of product also would seem to have a bearing on this.

DATA ON REFRIGERATION AND COLD STORAGE.

Total cold storage space (U. S. and Canada)	206,000,000 cu. ft.
Refrigerator and icing cars—number in U. S. and Canada	75,000
Refrigerated steamships—number in world	560
Refrigerating machines (1905), U. S. and Canada—	
Refrigerating capacity	354,000 tons per day.
Number of machines	9,036
" " Alaska and Yukon	14
" " Canada	194
Largest single unit (Swift & Co., Chicago), rated	750 tons per day.
Next largest, 2 units (Armour & Co., Chicago), each rated	600 tons per day.

MACHINES AND SYSTEMS.

The machines and systems in use include the compression system, the absorption system, and systems using ice and brine. The rating for production for these systems is as follows:

Compression system	70 per cent.
Absorption system	25 per cent.
Other systems	5 per cent.

The fact that there are eleven machines in use in Alaska emphasizes the well-recognized fact that the use of refrigerating machinery is not necessarily determined from the standpoint of the cost of natural ice, but rather by the fact that by its use results can be obtained that cannot be obtained in any other way.

CHAPTER II.

METHODS OF GENERATION.

THE ABSORPTION SYSTEM.

THE characteristic feature of the Absorption System is suggested by the name. The principle involved is the absorption of ammonia vapor or anhydrous ammonia by water. Anhydrous means destitute of water. Pure anhydrous ammonia at normal temperature and pressure is a colorless, pungent gas made up of one part of nitrogen and three parts of hydrogen. Ordinary ammonia, so-called, is aqua ammonia consisting of a solution of water with about 10 per cent. of ammonia, which would register about 16° Baumé. Strong aqua ammonia is used in the absorption system consisting of a solution of water and about 29.5 per cent. of ammonia, registering 26° Baumé, with a specific gravity of 0.897.

The series of operations involves four distinct stages or processes, respectively: the GENERATION of vapor; the CONDENSATION of vapor; the EVAPORATION or EXPANSION of liquid, and the ABSORPTION of vapor.

The absorption process consists of the formation of strong aqua ammonia by the reunion of anhydrous ammonia and weak aqua ammonia which have been separated in the generation process. These two processes are characteristic of the absorption system. The processes of condensation and expansion are common to other systems, and do not involve apparatus peculiar to the absorption system.

At the start the aqua ammonia is pumped from the iron drums in which it is delivered into the generator. The GENERATION involves through the application of heat to the generator the driving off of ammonia vapor, bringing up the pressure to from 120 to 160 pounds per square inch. Am-

monia driven off is, of course, in the form of vapor. At this pressure, by cooling, it may be reduced to a liquid. This is done in the next, the CONDENSATION process. For this purpose a condenser is used in which the ammonia is conducted through pipes which are brought in contact with cold water, either by having the water trickle over them, by being immersed in a tank with water, or with the pipes with ammonia arranged to enclose other pipes with water. Circulation of water is, of course, necessary for continuous operation. The ammonia gas gives up heat to the water, and is, in consequence, condensed to a liquid.

In the next, the EXPANSION process, the refrigeration is produced. This of course is to be carried out according to the circumstances as in any other process. In this process the liquid ammonia is allowed to pass through a valve which should be properly regulated into the net-work of pipes in the refrigeration chamber. The pressure in the expansion pipes is maintained low. The liquid ammonia at a high pressure, on admission to this system with low pressure, changes from a liquid to a vapor. The temperature at which this vaporization takes place depends upon the pressure. As the pressure is low the temperature of vaporization is also low. The heat required for vaporization is taken from the inclosing pipes, which in turn receive the heat from the surrounding space and goods, thus effecting the refrigeration desired.

The low pressure in the refrigerating coils is maintained by the absorption of the anhydrous ammonia by the weak aqua ammonia, which, after being deprived of anhydrous ammonia in the generator, is delivered to the absorber, in the ABSORPTION process. The strong aqua ammonia thus formed in the absorber is delivered by a pump to the generator, where it is ready to go through the same series of operations again.

It is to be noticed that the only mechanically operated feature of the absorption system is the pump used to pump the aqua ammonia into the generator. As this is but a

diminutive affair, it will be seen that this system shows a decided contrast to the methods employed by the compression system, in which mechanical operation really constitutes the base of the system.

In practical operations, other features are introduced to im-

FIG. 1.

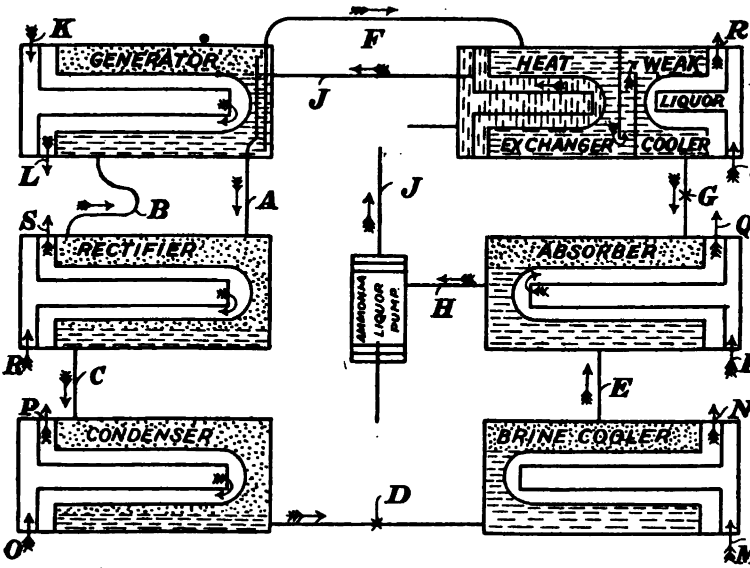

DIAGRAM OF THE ABSORPTION SYSTEM.

A. Wet ammonia gas from generator.
B. Drain-pipe from rectifier.
C. Anhydrous ammonia gas to condenser.
D. Expansion valve for anhydrous liquid ammonia.
E. Ammonia gas to absorber.
F. Weak liquor from generator to exchanger.
G. Weak liquor regulating valve.
H. Strong liquor to pump.
J. Strong liquor through exchanger to generator.
K. Steam inlet.
L. Condensed steam outlet to steam-trap.
M. Brine inlet.
N. Brine outlet.
O, P, Q, R, S. Cooling water circuit.

prove efficiency and economy. Two of these are shown in the diagram shown in Fig. 1, namely, the rectifier and the heat-exchanger. The function of the rectifier is to precipitate moisture, so as to improve the anhydrous qualities of the vapor. The heat-exchanger is utilized to economize heat by

means of transfer of heat from the weak liquor to the strong liquor. The weak liquor is en route from the generator, where it has been subjected to heat, to the absorber, where it is to be subjected to a reduction in temperature by means of water circulation. The conditions in regard to the strong liquor are of course just the reverse. Accordingly, any heat transferred from the strong liquor to the weak liquor represents just so much gain in economy.

The brine cooler shown represents an apparatus used in one method of utilizing the refrigerating effect, in which the brine is cooled by the primary cooling medium, which in turn is circulated to produce the refrigeration desired. This, in accordance with the statement made above, is not peculiar to the absorption process.

Following the diagram shown in Fig. 1, the process is as follows: The ammonia vapor, which is evaporated in the brine cooler by the extraction of heat from the brine, passes into the absorber by the pipe *E*. Here it is absorbed by the weak liquor, being cooled meanwhile by the circulating water, as the liquor only takes up ammonia at a low temperature. The liquor is withdrawn by the ammonia pump and forced into the heat-exchanger. In this vessel, as stated above, it abstracts heat from the weak liquor, attaining the double object of increasing its own temperature and diminishing that of the weak liquor. The heat-exchanger is also provided with water circulation, which still further cools the weak liquor in readiness for the absorption process. From the heat-exchanger the strong liquor passes into the generator on the pipe *J*. This vessel is provided with a steam circulation, which still further raises the temperature of the strong liquor, driving off the ammonia as vapor, and leaving the liquor weak. This is the source of the weak liquor, which we have seen cooled in the exchanger and then used in the absorber.

THE AMMONIA COMPRESSION SYSTEM.

Of the systems of artificial production of ice and mechanical refrigeration in extensive use to-day, the ammonia com-

pression system undoubtedly occupies a pre-eminent position. The medium or refrigerant used is anhydrous ammonia.

The process consists of a complete cycle involving three successive steps. They are called respectively COMPRESSION, CONDENSATION and EXPANSION. These three steps are made continuous, and are constantly repeated. The ammonia is kept confined. Thus the same ammonia is used repeatedly, the supply simply being replenished from time to time, as losses unavoidably occur.

At the beginning the ammonia is in the form of vapor, and at not far from the atmospheric pressure and temperature.

For the COMPRESSION process a compressor is used, which is nothing more or less than a specially designed pump. The compressor is used to compress the ammonia vapor to a pressure of from 125 to 175 pounds per square inch. The vapor in the beginning, as in the case of bodies in general, contained a certain amount of heat. After compression it contains practically this same amount of heat and in addition the heat representing the equivalent of the work of compression. In this condition the ammonia is still maintained in the state of vapor or gas, notwithstanding the high pressure, owing to its containing what is called excess heat. Hence at the end of the compression process, the ammonia is still a gas or vapor.

The next, or CONDENSATION, process consists in removing this excess of heat. For this process a condenser is used. This consists of an arrangement of pipes for the ammonia, in contact with cold water. The ammonia gives up the excess of heat to the cold water, and is in consequence reduced to a liquid.

It is in the EXPANSION process that the refrigeration is produced. What might here be called the refrigerator consists of a net-work of pipes arranged according to results desired. The compressor draws its supply of ammonia from these pipes. In consequence the pressure in the same is maintained comparatively low, being possibly from 25 to 55 pounds per square inch. The liquid ammonia at the high pressure given is allowed to enter these pipes with low pressure. The result is

that the ammonia, being relieved of the high pressure, changes from a liquid to a vapor, at a low temperature, corresponding to the pressure. The heat of vaporization is absorbed from the enclosing pipe system. As the pipes are supposed to be arranged in the spaces to be cooled, these supply the heat which the ammonia absorbs, thus becoming reduced in temperature and accomplishing the results desired.

FIG. 2.

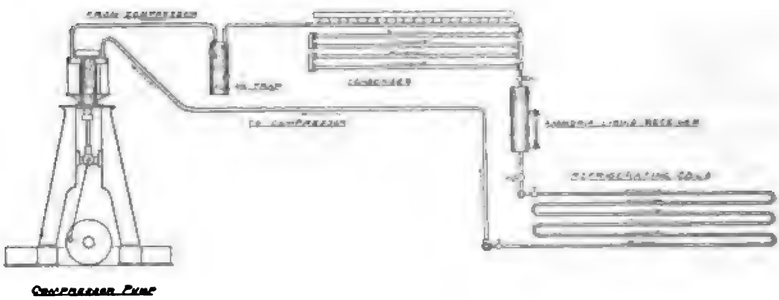

DIAGRAM OF THE COMPRESSION SYSTEM.

The process will be readily understood from the diagram shown in Fig 2.

ANHYDROUS SULPHUROUS DI-OXIDE SYSTEM.

The general distinction of the anhydrous sulphurous di-oxide system as regards the ammonia compression system, is simply in the medium or refrigerant used, which is, as may be inferred from the name, sulphurous di-oxide. From its chemical symbol SO_2, it is seen that it consists of one part of sulphur to two parts of oxygen.

The working pressure, however, in the SO_2 system is less than that of the ammonia system by from one-half to one-third. Furthermore, there is a difference in the effect of the two materials upon metallic substances. Thus, ammonia has a peculiar action upon copper and alloys of copper, as brass. Consequently, iron or steel must be used in parts of the system that come in contact with the ammonia. As SO_2 has no such effect on any of the metals that have been mentioned, this

material may be used in apparatus using ammonia and in cases where ammonia could not be used. Accordingly, copper pipes may be used for the condenser and refrigerating coils with SO_2 as the refrigerant. This is especially advantageous where the water used for condensation contains ingredients that have a tendency to deteriorate iron or steel. Copper is a very desirable material to be used, from many standpoints. It is contended, however, that the apparent advantage of the ability to use copper may be off-set in the ammonia system by the use of the requisite additional amount of piping of iron or steel, and at an advantage as regards expense.

With systems properly designed, there is no practical difference in efficiency between the ammonia and the sulphurous di-oxide systems.

THE CARBONIC ANHYDRIDE SYSTEM.

A general description of the ammonia compression system and one of the carbonic anhydride systems would differ only in regard to the refrigerant used. As may be inferred from the name, in the carbonic anhydride system the refrigerant used is carbonic anhydride, which is commonly known likewise as carbon di-oxide and carbonic acid gas. It is a non-poisonous gas, and is a constituent of the atmosphere. A marked feature of the system is the enormous pressure used, varying in amount in different climates, from 750 pounds per square inch in temperate climates, with water at fifty degrees Fahrenheit, to about 1,125 pounds, with water at 84 degrees, in tropics.

This enormous pressure is required on account of the peculier characteristic of carbonic anhydride, which is only liquefied under high pressure. This feature has its advantages as well as its disadvantages. Corresponding with this high pressure is smallness of the dimensions of the compressor, which accordingly is made compact and can be readily made of requisite strength.

An important feature of the carbonic anhydride process is the fact that on account of the non-poisonous nature of the

medium, it is possible to introduce a safety-valve in the system, a welcome addition to any pressure system.

THE COMPRESSED AIR SYSTEM.

The characteristic feature of the compressed air system is involved in the fact that the medium, air, is not condensed to the liquid state.

The air is first compressed, during which process heat is generated. This heat is abstracted in an apparatus similar to a condenser. The term condenser cannot be correctly applied, simply for the reason that no condensation of the medium is produced. The refrigeration of the air is produced by allowing the compressed air to re-expand while doing work. This re-expanded air is reduced in temperature. This cold air is circulated in the refrigerating coils to perform the refrigerating duty desired. The principle of thermo-dynamics involved is that when a gas is allowed to expand doing work, the amount of heat given out by the gas is equivalent in mechanical energy to the work done. When the air is compressed, the amount of heat generated is equivalent in mechanical energy to the work of compression. In practice, of course, the usual inevitable losses attendant upon any transformation of energy tend to reduce the value of the effective results.

The essential parts of a compressed air plant are as follows:

A *Prime Motor*, as a steam engine, as a source of motive power;

A *Compressor*, which compresses the air;

A *Cooling Apparatus*, consisting generally of a coil of pipe containing the compressed and heated air, managed so as to be cooled by a flow of water;

An *Expander*, consisting of a cylinder, piston and valves, arranged similar to those of a steam engine, with cut-off, into which the cooled compressed air is admitted during a portion of the stroke, the air acting expansively during the remainder of the stroke, and thereby being reduced in temperature. On the return stroke this cooled air is expelled; and

A *Refrigerator*, the last of the series, which may consist of

coils of pipe which receive the cooled air expelled from the cylinder. These coils are of course arranged as in refrigerating plants generally to produce the results desired.

From the refrigerator the air passes again to the compressor, to be again started through a repetition of the cycle of operations just enumerated. For successful operation should also be included traps for the separation of oil and snow from the cold air, and for separating moisture from freshly supplied air, and provision for water-jacketing the compressor cylinder. The piston rod of the expanding cylinder may be connected through a connecting rod to a crank on the main shaft, so that the work of the expanding air is used to assist the steam in operating the plant.

The refrigeration may also be produced by releasing the cooled air directly into the chambers to be cooled. In this case the air is drawn from the refrigerator chambers by the compressor. This method was once extensively used on shipboard. Considerable difficulty was encountered in this method from the snow formed in the apparatus by the condensation of moisture contained in the air.

CHAPTER III.

METHODS OF APPLICATION.

REFRIGERATION.

THE methods of refrigeration may be conveniently classified in two classes, respectively known as the direct and indirect. In the case of the direct system the evaporator is placed directly in the rooms or chambers which it is desired to cool. Thus, when the refrigerant is allowed to expand in the coils of the evaporator, the surrounding pipes are cooled, and absorb heat from the surrounding chamber, effecting the cooling as desired.

In the case of the indirect system a secondary medium is employed to produce the refrigeration desired. As generally understood the term indirect system refers to the system employing brine for the secondary medium. The brine may be made up with either sodium chloride (common salt) or calcium chloride.

In this system the evaporating coils are arranged so as to be in contact with strong brine. The vaporization of the refrigerant results in cooling the brine, which is circulated through a pipe system arranged to produce the refrigeration desired.

The arrangement of piping for cooling is quite similar in the direct system and the indirect brine system.

A special case in the indirect system is known as the indirect air system. In this system the circulating medium for producing the refrigeration desired is air, which is cooled by passing over pipes which are cooled either by the direct system or the indirect brine system. These cooling pipes are grouped in a room, called the bunker room.

These various systems have each their advantages as well as disadvantages, so that which is really best depends upon prevailing circumstances.

A representation of an ammonia compression plant employing the direct system is shown in Fig. 2 and Fig. 3. The

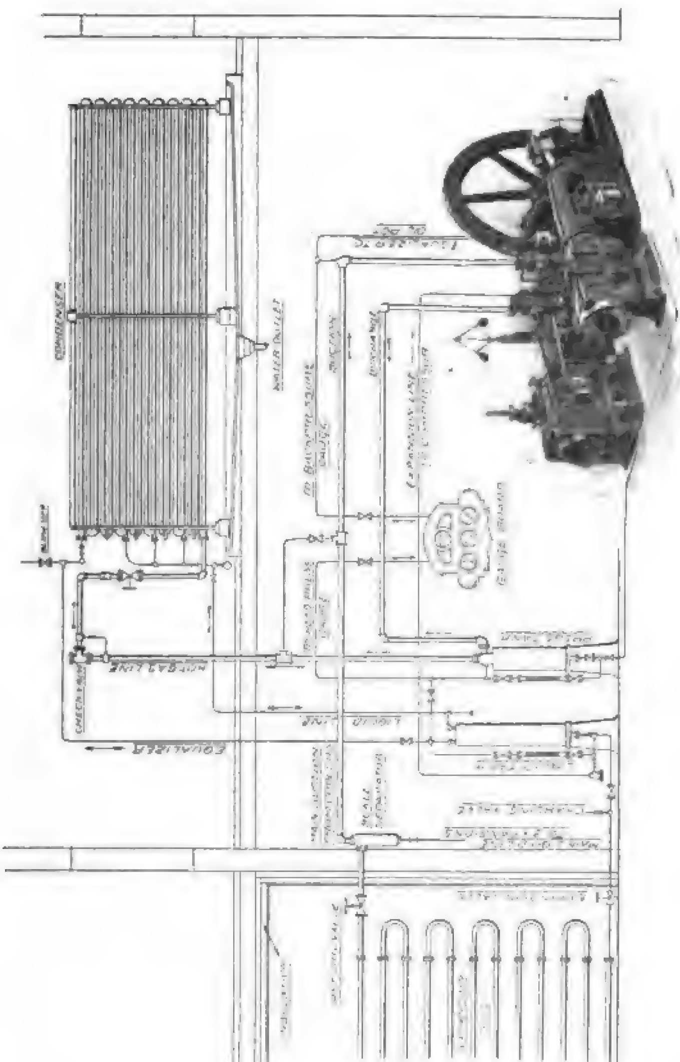

FIG. 3.

GENERAL ARRANGEMENT OF REFRIGERATING PLANT.

principal elements of a plant of this kind are the compressor pump, the condenser, the expansion valve and the system of

refrigerating coils arranged for distributing the refrigerating effect as desired.

An arrangement of the indirect brine system in a packing house is shown in Fig. 4. The additional parts required for this system are the brine tanks, designated as refrigerators in the illustration, and the brine pump for the circulating of the cooled brine in the network of piping located in the refrigerated chambers.

In the case of the indirect air system the special features are the bunker rooms, with a nest of cooling coils and blowers used for maintaining the air in circulation.

The signs of the times seem to indicate the coming into favor of the indirect brine system as against the direct expansion system. This may be due in part to finding the weak places in the direct system, but for the most part seems to be due to the strong points of the brine system.

One of the points in favor of the direct system is smaller installation expense, due to omission of pumps and tanks. Another is smaller operating expense, due to a smaller range in temperature for the same refrigerating effect. These advantages hold good in many cases, especially where conditions are quite steady, and not liable to fluctuations.

Where such fluctuations are liable to occur or where there may be desire or need to interrupt the operation of the machinery the indirect brine system is the better adapted to meet the situation. In fact this system is best adapted for all-round use. Results are after all the criterion. With these assured, and with the advantages of the direct system largely eliminated by modern methods, there is no doubt of the pre-eminent position held by the indirect brine system.

A few of these pros and cons may be worthy of mention.

1. The advantage of cost of installation holds in favor of the direct system, on account of extra cost for brine tanks and pumps.

2. The cost of operation is not so clearly in favor of the direct system. From a thermodynamic point this would be the case, and it would hold in the case of large plants, that

Fig

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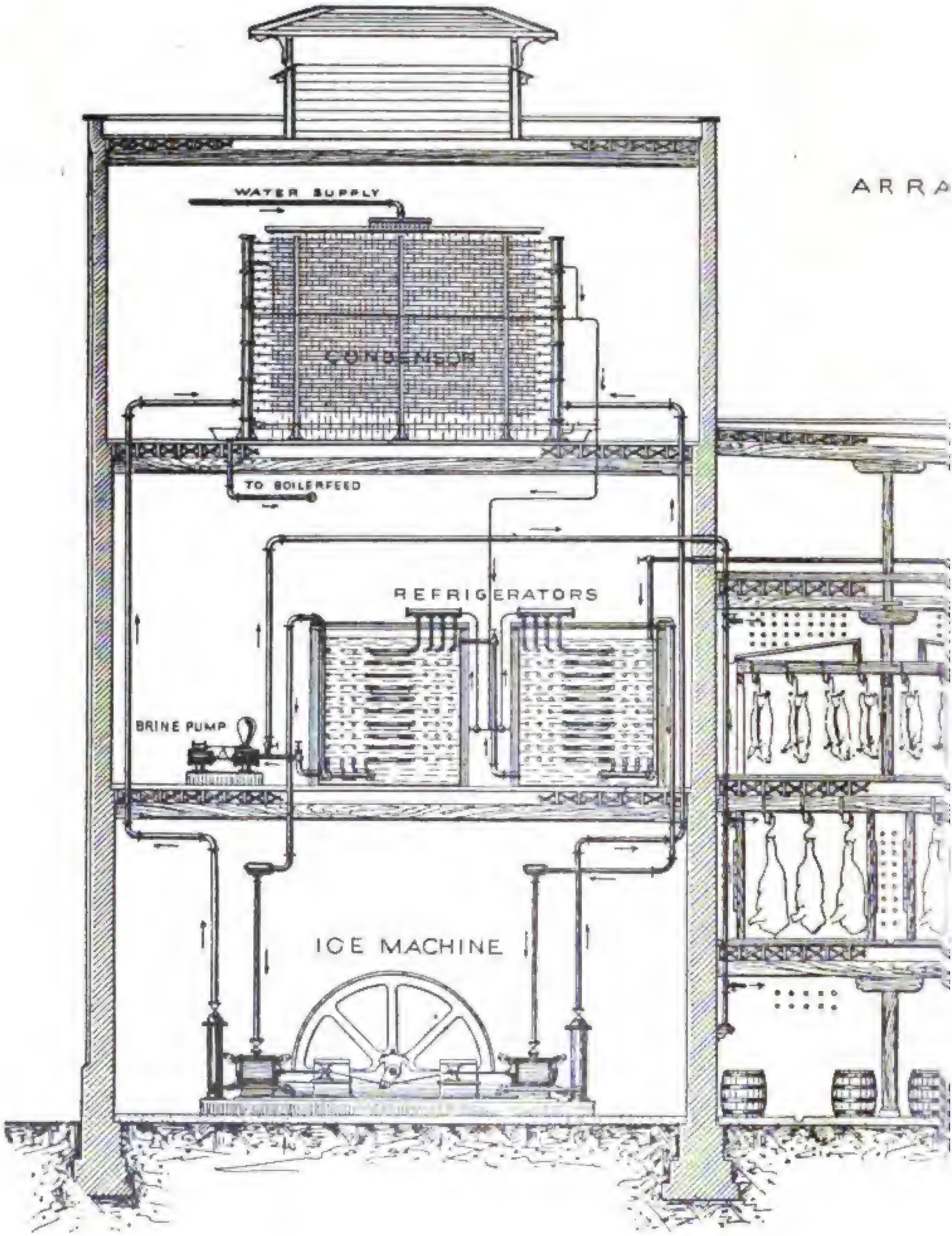
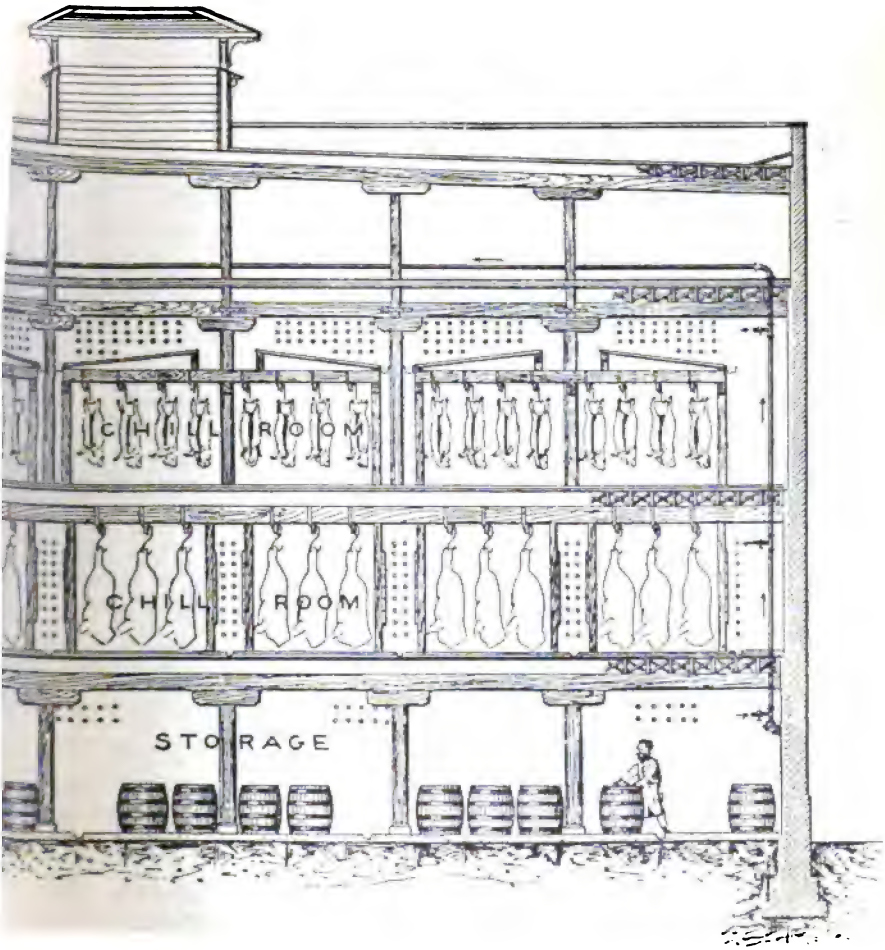


WATER SUPPLY
CONDENSOR
TO BOILERFEED
REFRIGERATORS
BRINE PUMP
ICE MACHINE

EMENT OF BRINE SYSTEM IN PACKING-
AND COLD STORAGE HOUSES.



(To face p. 18.)

could be readily maintained in operation night and day. In the case of small plants, by using the indirect system, it is possible to limit the operation of the general plant and the services of the engineer to the regular working day with the refrigeration maintained uninterrupted by means of the circulating pump for the brine. This pump is a rather diminutive affair and may be readily looked after by the night-watchman.

3. The results obtained from a refrigeration standpoint are clearly in favor of the indirect system. This is due to the fact that in the indirect system the refrigeration is effected by brine which has an extreme variation of temperature of only 4° or 5° F., whereas the temperature in the expansion coils may vary from the low temperature due to the pressure to a temperature involving superheat. It is better to have this large variation in temperature taken up in the brine tank than in the refrigerator.

In case of accidental interruption of operation of the compressors in the direct system the only reserve for refrigeration is the accumulation of ice on the expansion coils. With extended interruption this ice would melt, resulting in an increase in the humidity, which would be detrimental generally to the goods in storage.

4. On the score of liability to leaks and losses attendant upon the same it would seem as if the indirect system had the advantage. The record for serious losses in the direct system has not as a matter of fact been sufficiently bad to cause a general condemnation of the system. Nevertheless the liability to leakage would be greater with the direct system on account of the higher pressure.

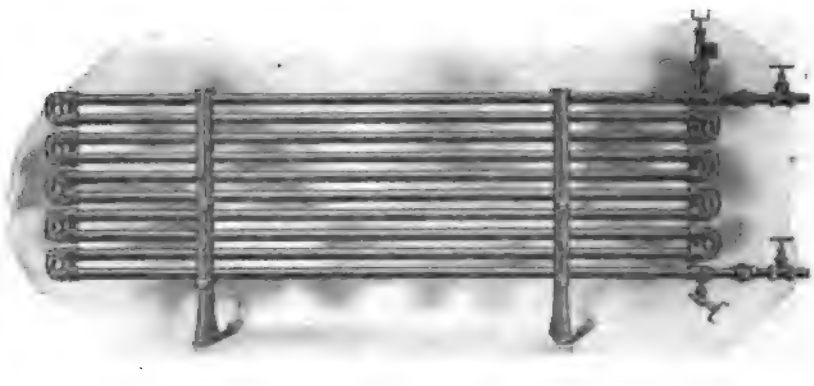
As to consequences, those from an ammonia leak are certainly more formidable than a leak in a brine pipe. In the expense from loss of material, of course, the loss of brine is not to be compared with the loss of ammonia. The danger from fire and damage to goods have been rather exaggerated. There is undoubtedly some danger of loss of life from escaped ammonia.

The safe-guard in either case is, of course, good piping, good fittings and good workmanship.

5. The item of expense for ammonia for charging the system is much less for the indirect than for the direct system.

6. Troubles with the regulating or expansion valves are reduced to a minimum with the indirect system, partly from the fact that the number of such valves has been materially reduced and furthermore because with this reduced number those that are used have larger passageways for the ammonia and are therefore less liable to give trouble.

FIG. 5.



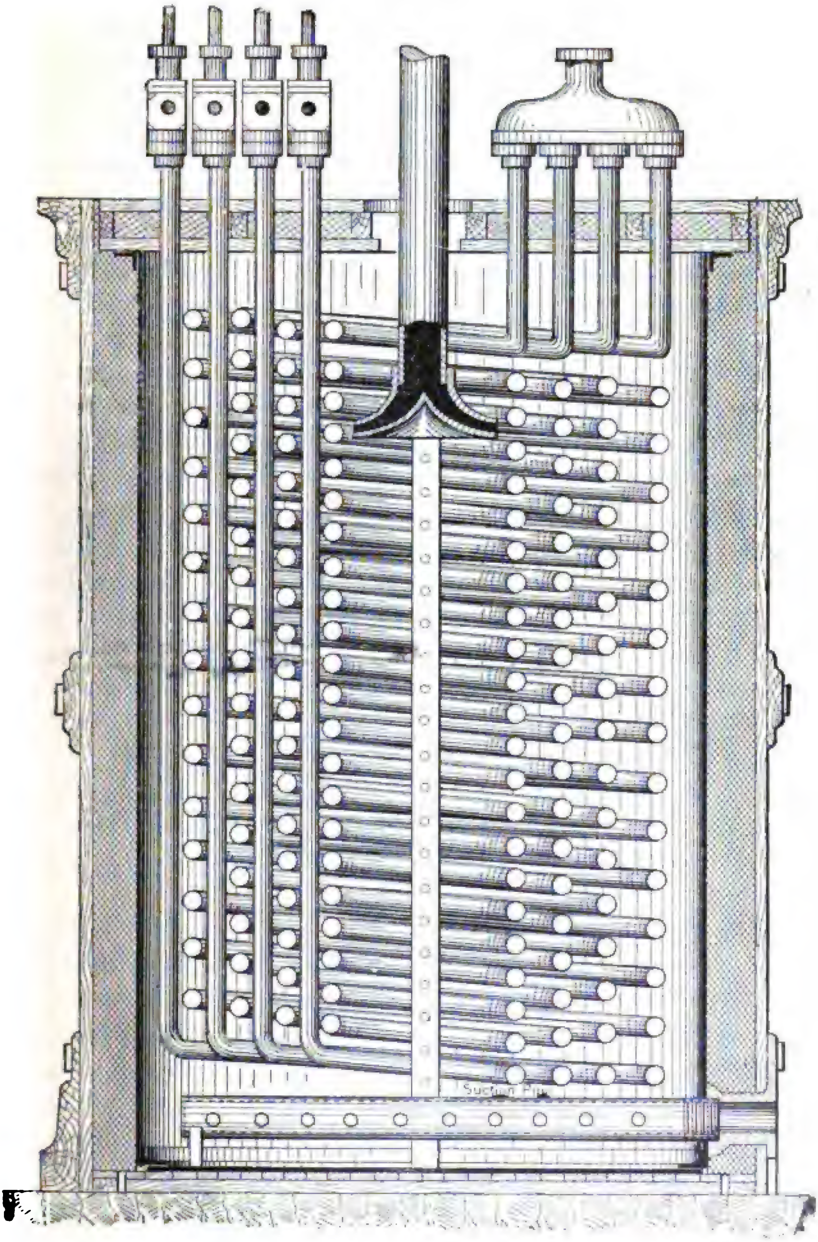
THE TRIUMPH BRINE COOLER.

7. Where refrigeration and ice-making are combined it is possible to use the same brine tank for brine supply for the freezing tanks and the brine circulation in the refrigerators.

8. In the case of the indirect method the brine tank and pump would be located near the engine room, so that all the high pressure system would be readily accessible to the engineer.

One of the important recent improvements in the indirect system was the introduction of the brine cooler of double pipe construction, such as shown in Fig. 5. The advantages of this apparatus over its predecessor, the brine tank, Fig. 6, are the same as the advantages that have served to make this class of

FIG. 6.



BRINE TANK.

Showing likewise the General Arrangement of the Submerged Condenser.

apparatus so popular at the present time. These include economy and efficiency, ease of inspection and cleanliness. Following from the latter is the ability to locate the apparatus practically at any place where there happens to be space available.

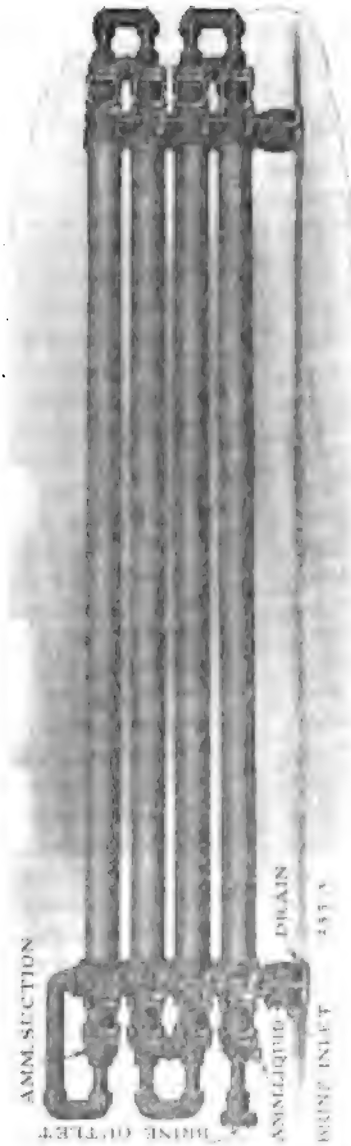
The merits of the double pipe brine cooler are surpassed by those of the apparatus shown in Fig. 7, which represents a triple pipe brine cooler.

One decided improvement in recent practice is the adoption of brine made with calcium chloride ($CaCl_2$) instead of sodium chloride or common salt ($NaCl$). The result though obtained at somewhat higher first cost, is longer life to the piping and apparatus in contact with the brine. An inspection of the tables giving the properties of these two ingredients will show that it is possible to maintain lower temperatures with calcium brine. With the increasing demand for lower expansion temperatures, both for refrigeration and for ice making, the use of calcium brine is practically required. Magnesium chloride could be utilized so far as its physical properties are concerned, but the cost is prohibitive.

Another advance in the indirect system not as yet generally introduced is the use of the brine in the refrigerated spaces in direct contact with the air instead of enclosed in pipes. There are good points in this method both from the standpoint of cost of installation and results produced. This method is being tried out in practice and the results obtained are promising for the future.

The indirect air system, known also as the chilled air system or the cold air circulation system is used where it is desired to obtain the advantages of improved ventilation and the increased efficiency due to air in circulation. These advantages are desirable in any case, but are especially so in the case of certain classes of goods in storage, such as eggs, cheese, fruits, meats and perishable goods generally. This is the method employed for cooling the air for auditoriums or for the work rooms in special industries, such as chocolate factories.

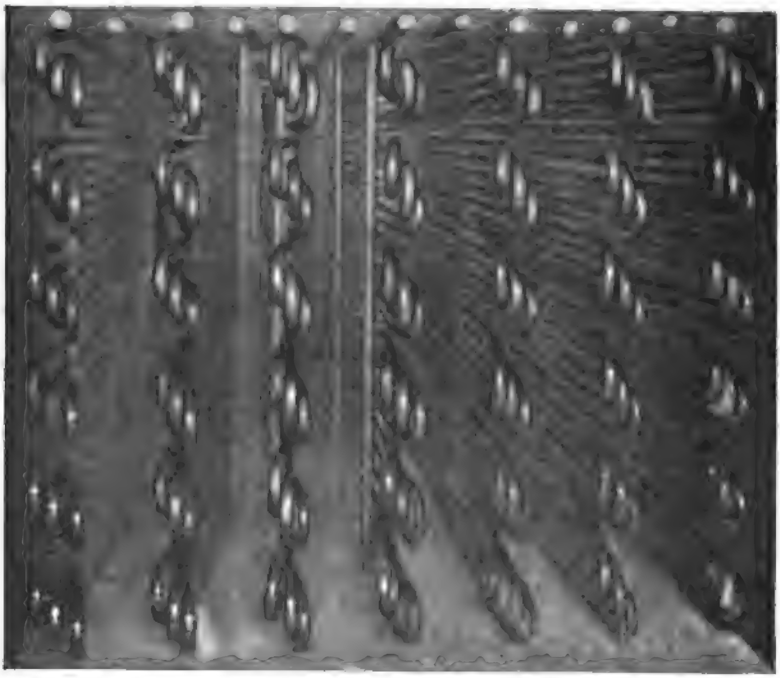
FIG. 7.



ECLIPSE PATENTED TRIPLE-PIPE BRINE COOLER.

The bunker rooms may be equipped with coils for ammonia direct expansion, or brine. In addition to these coils excellent results are obtained by having brine dripping over the coils to prevent the accumulation of ice. An interior view of a bunker room operated on this plan is shown in Fig. 8.

FIG. 8.



This latter system has been adopted exclusively in some large modern plants, so that the merits of the same have been conclusively demonstrated on a large scale.

CHAPTER IV.

APPLICATIONS OF REFRIGERATION.

An enumeration of the industries employing mechanical refrigeration would be too extensive to be other than monotonous. In our attempt to do some justice to this subject we will confine ourselves to a list of some of these places and industries and a brief reference to some of the typical cases to bring out the essential features.

SOME OF THE PLACES WHERE ICE-MAKING AND REFRIGERATING MACHINERY IS USED.

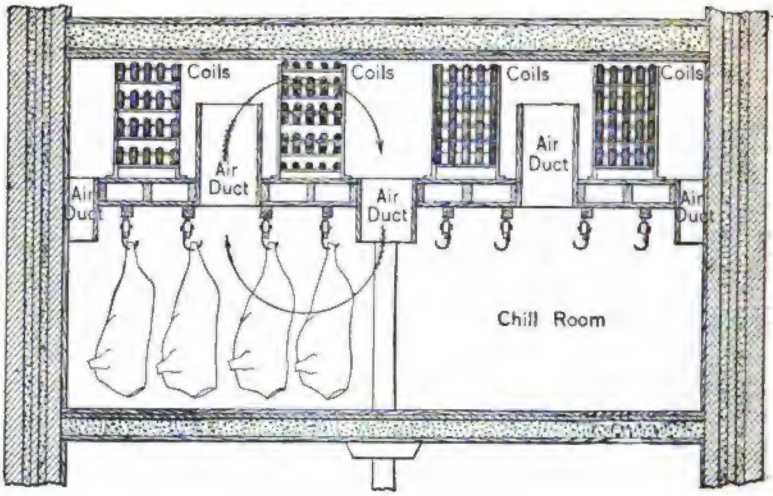
Can ice-making plants,	Chemical works,	Ocean vessels,
Plate ice-making plants,	Sugar refineries,	Apartment houses,
Beer breweries,	Paraffine works,	Office buildings,
Ale breweries,	Oil refineries,	Molasses factories,
Cold-storage houses,	Lard factories,	Skating rinks,
Groceries,	Distilleries,	Steel tempering,
Markets,	Laundries,	Blast furnaces,
Packing houses,	Glue works,	Dry-plate works,
Abattoirs,	Wineries,	Dynamite works,
Fish-curing plants,	Fur storage,	Stearine factories,
Dairies,	Hotels,	Chocolate factories,
Butter factories,	Restaurants,	Paint factories,
Milk depots,	Theaters,	Soap factories,
Butterine factories,	Hospitals,	Seasoning lumber,
Ice-cream factories,	Morgues,	India-rubber works.

ABATTOIRS AND PACKING HOUSES.

The introduction of mechanical refrigeration in abattoirs and packing houses marked a new era in these industries, and has resulted in a revolution in the arrangement of buildings and the methods of caring for fresh killed hogs and beef and the storage of the carcasses. The removal of a large quantity of animal heat rapidly and at the same time grading

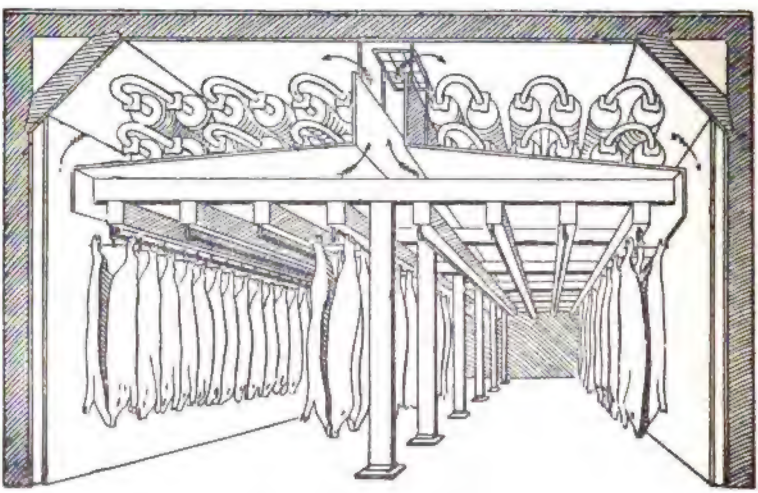
the temperature to ensure proper curing, by a uniform chilling throughout, could not be brought about by any other process.

FIG. 9.



CHILL ROOM.

FIG. 10.



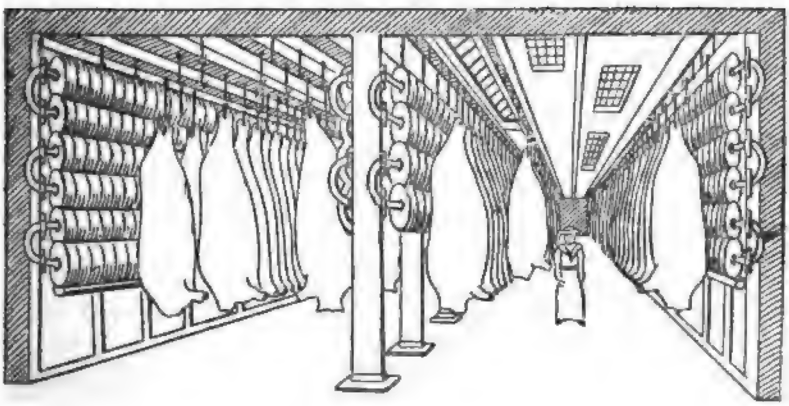
CHILL ROOM FOR HOGS.
Piping in Overhead Chambers (De La Vergne System).

The preferable arrangement of piping is in lofts overhead with protecting ceilings for drip and ducts for circulation of air as shown in Fig. 9 and Fig. 10.

In some cases, as where old establishments are made over for mechanical refrigeration, it may be more convenient to have the coils arranged along the sides of the walls as shown in Fig. 11.

Instead of piping in this way a hollow plate or wall is also used in which cold brine is circulated.

FIG. 11.



CHILL ROOM FOR BEEF.

Piping with Radiating Discs. Piping along side of room.

Satisfactory results are obtained by any of the methods that have been indicated.

COLD STORAGE.

To the development of artificial refrigerating machinery and the refrigerator car may be credited the development of cold storage, a new industry. Enormous as this industry has grown, a further expansion on a grand scale is one of the certainties of the future. It must operate on the whole to the mutual advantage of the producer and the consumer. In periods of over-production it enables the producer to avoid an over-

stocked market, and the resulting necessity of disposing of his goods at ruinous prices. The apparent loss to the consumer of the possibility of purchasing at abnormally low prices is compensated for by the lower prices prevailing when the conditions mentioned are reversed. In fact the cold storage industry has a steadying effect upon the market, and upon prices generally, and consequently is a welcome acquisition to the world of commerce.

The safe transportation of perishable articles in refrigerator cars has, in itself, been a very important problem, the practical solution of which has involved a great deal of thought and ingenuity, but in the absence of cold storage warehouses, the food-stuffs would have to be shipped as soon as produced and consumed as soon as delivered in town. Now, however, the goods can be held till the market is ready for them. The result is equally advantageous to the farmer and to the consumer.

Moreover, not the least advantage of the system of holding foodstuffs in cold storage is the fact that, being perfectly good security, the capital required for carrying the large stocks necessary to equalize the markets is readily obtainable.

The tendency in regard to storage temperatures is to use as low temperatures as the product can stand. Wherever actual freezing can be employed without danger to the product this is obviously the safest and most convenient method. Experiment has shown that freezing may be safely practised where it has been previously condemned as detrimental, as for example in the cases of butter and milk.

Lists of proper temperatures for various classes of goods sometimes given out are only to be regarded as approximate. The degree of temperature to be maintained varies, of course, for the different products, and even for the same class of goods, according to previous handling and to final destination. Accordingly, the proper handling of any line of goods calls for the display of judgment, and involves experience and study.

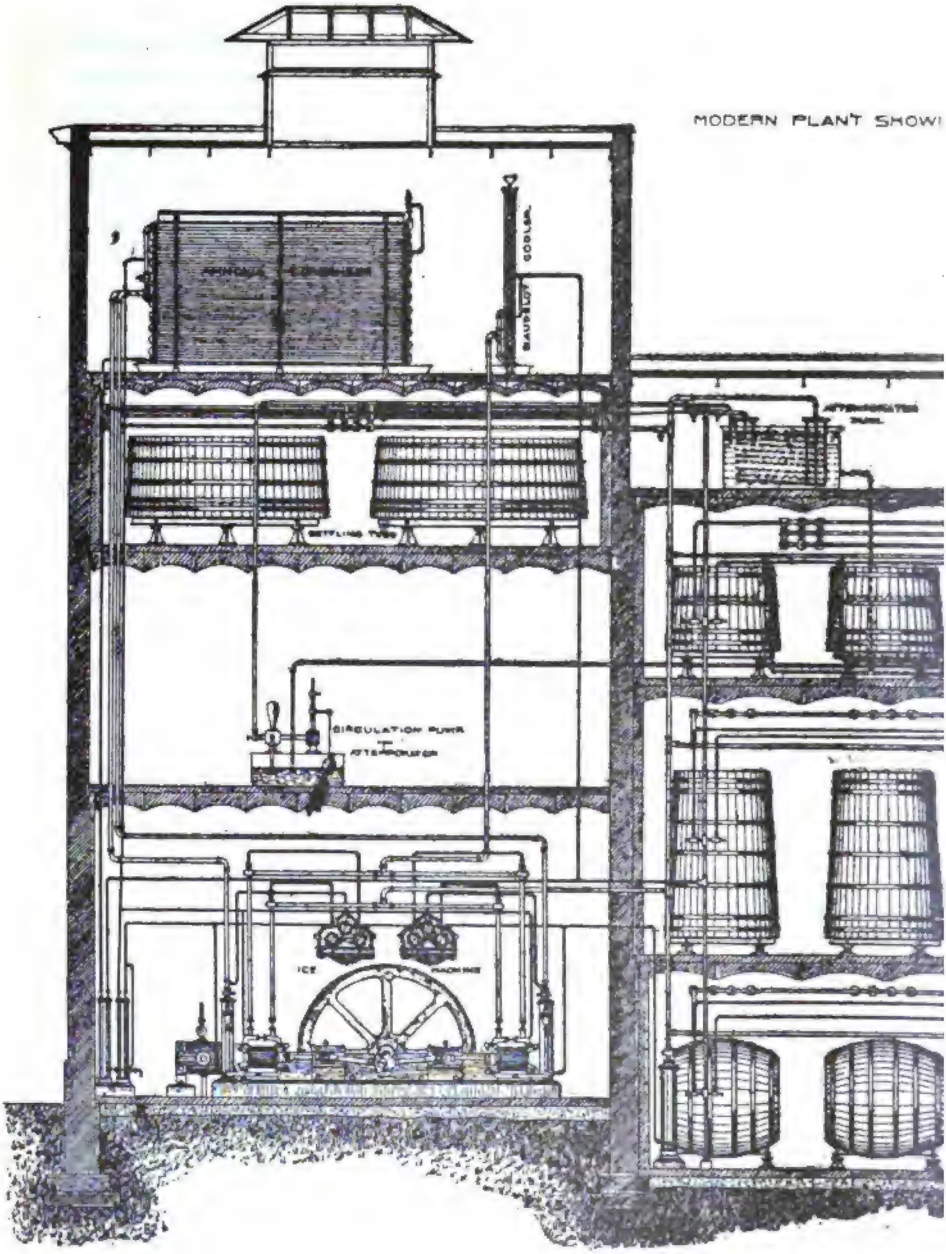
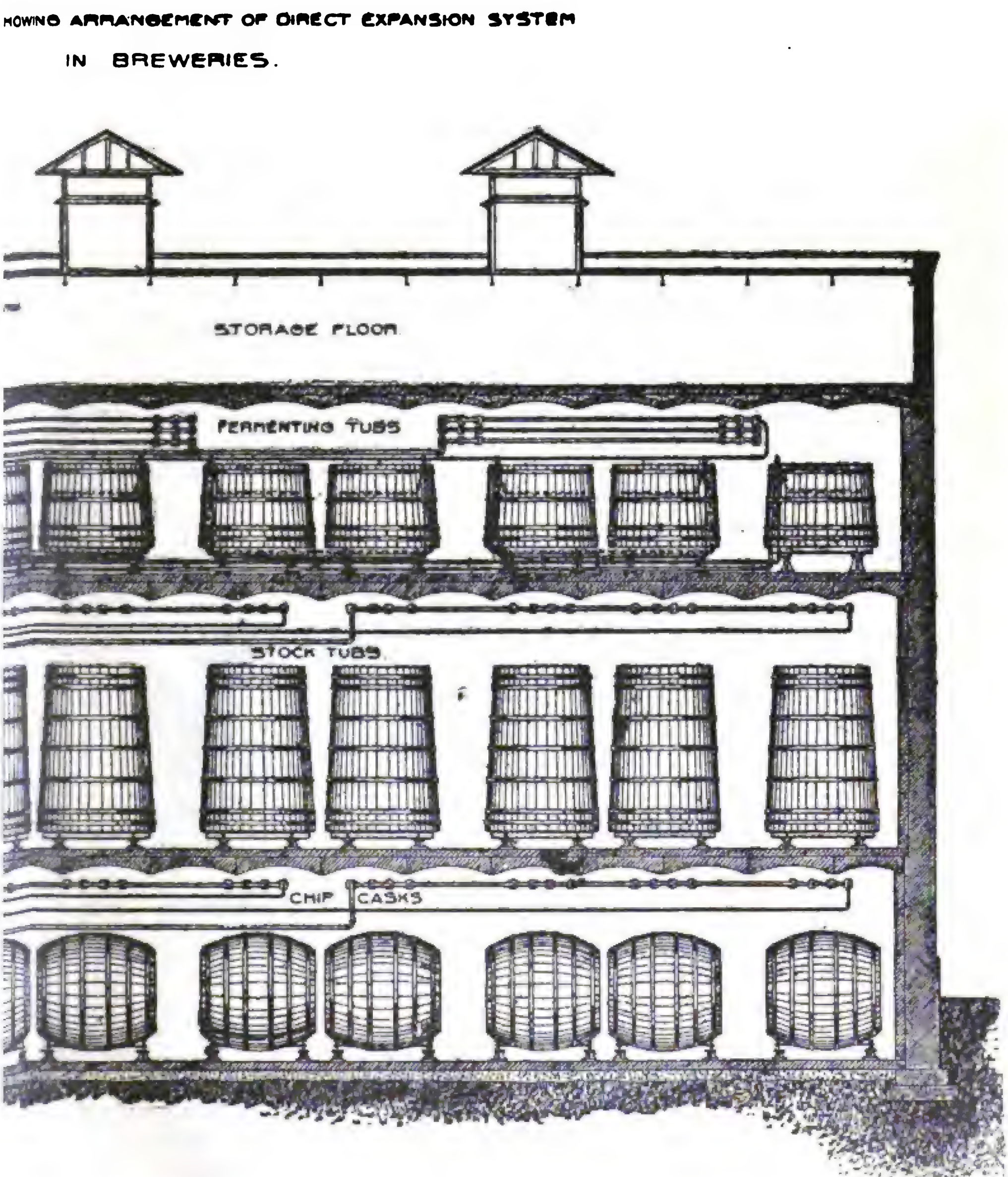

MODERN PLANT SHOWI
COOLER
CIRCULATION PUMP
ICE

Fig. 12.



(To face p. 28.)

BREWERY REFRIGERATION.

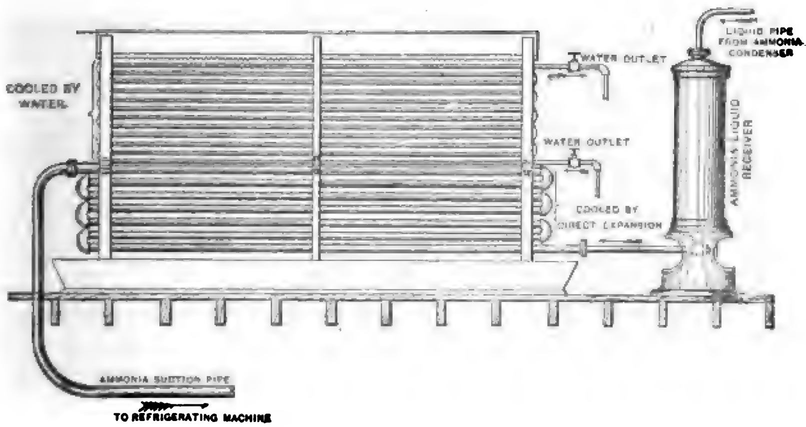
The modern brewery is as intimately involved in the processes of mechanical refrigeration as the modern packing-house or cold storage warehouse. Extensive use is made of the ordinary processes of refrigeration for the preservation of products and also of ice-making for the production of ice for use on the premises or for the packing of goods for shipment. In addition there are special adaptations of the process to features peculiar to the industry, as in the Baudelot cooler and in the attemperators.

An arrangement of a plant operating on the direct expansion system is shown in Fig. 12.

BAUDELOT COOLER.

The Baudelot cooler is used for cooling the hot beer wort in preparation for fermentation. The importance of economical

FIG. 13.

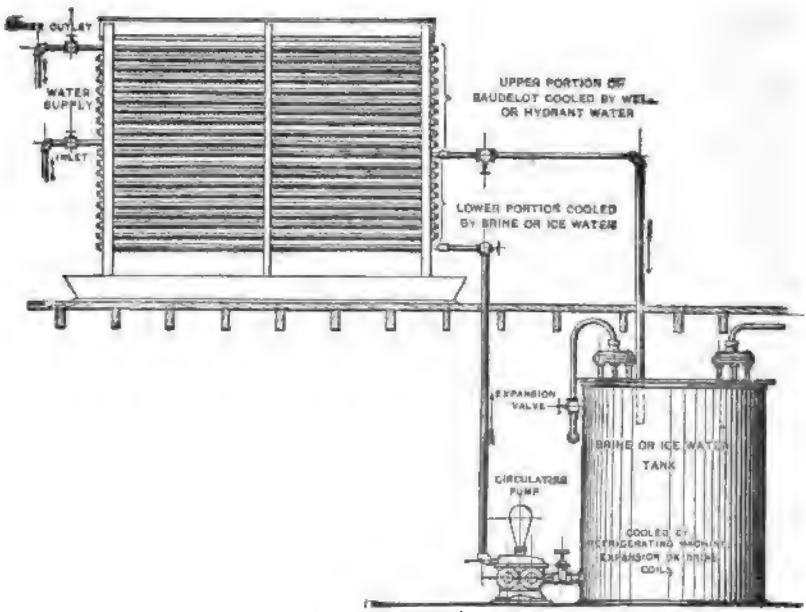


DIRECT EXPANSION BAUDELOT COOLER FOR BEER WORT. COLD WATER USED IN THE UPPER PART.

and efficient methods in this apparatus are appreciated when it is understood that the work required in reducing the temperature of the wort amounts to almost one-third of the entire refrigerating work of the brewery and usually to more than the work done in the rest of the brewery during the time the wort is being cooled.

The Baudelot cooler as originally constructed was made up of a vertical column of pipes of copper for conveying the cooling medium. The wort is admitted at the top, trickles over the outside and becomes cooled in its descent. The piping is divided horizontally in two sections. In the upper section hydrant or well water is used for cooling. There has been no change in this section. In the lower section ice water was originally used. This has been replaced by either ammonia

FIG. 14.

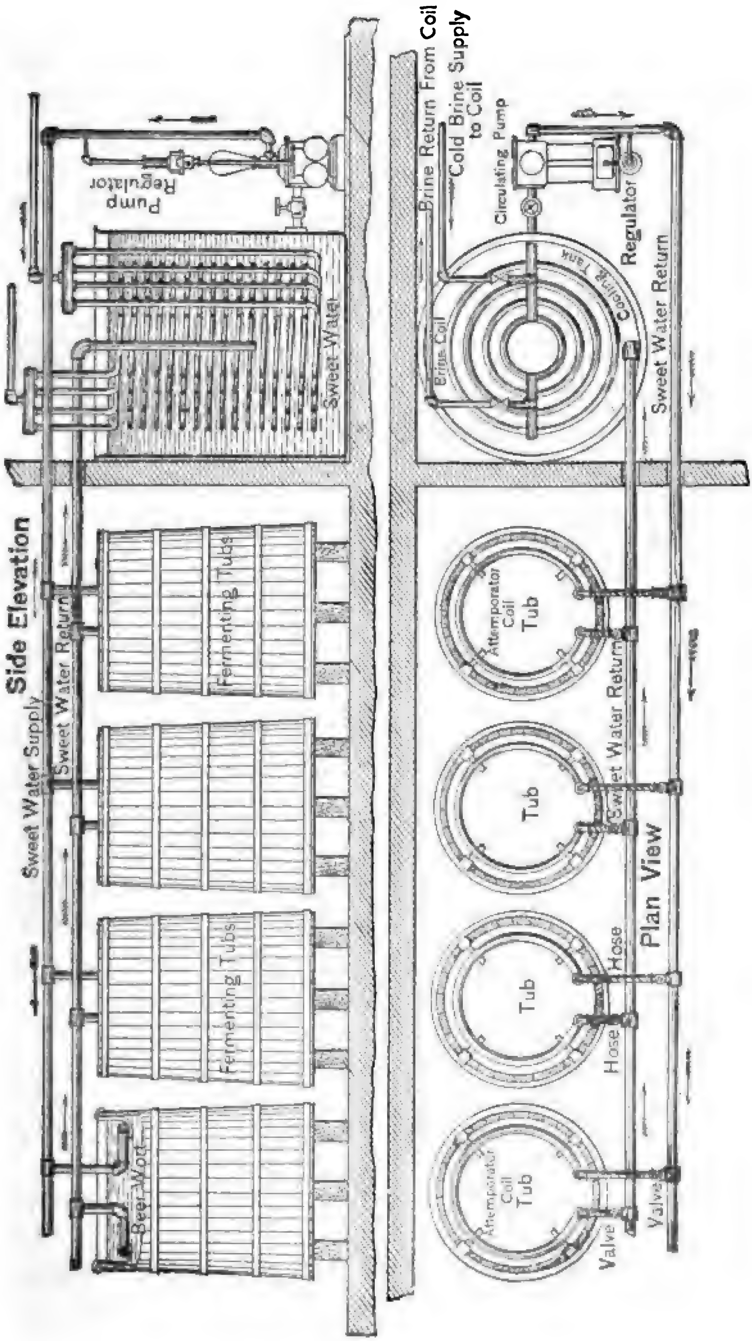


BRINE BAUDELOT COOLER FOR BEER WORT. COLD WATER USED IN UPPER PART.

vapor with direct expansion or brine with indirect refrigeration. These two methods are shown respectively in Fig. 13 and Fig. 14.

As copper piping cannot be used with ammonia this is replaced in some cases by iron pipe enclosed in copper. As there is loss of efficiency in this arrangement, as well as high cost, preference is given of late to plain iron pipe, ground bright with an emery wheel. A coating is imparted to the outside of these pipes by the wort after use a few times which prevents corrosion of the surfaces.

FIG. 15.



AUTOMATIC ATTEMPORATOR SYSTEM FOR REGULATING FERMENTATION.

THE ATTEMPERATOR.

The attemperator is used for cooling the beer while in fermentation. It consists of a coil of iron or copper pipe or hollow-walled cylinder supplied with circulating cooling water arranged to be submerged in the vats containing the beer. The cooling water that is circulated in the coils is fresh water,

FIG. 17.

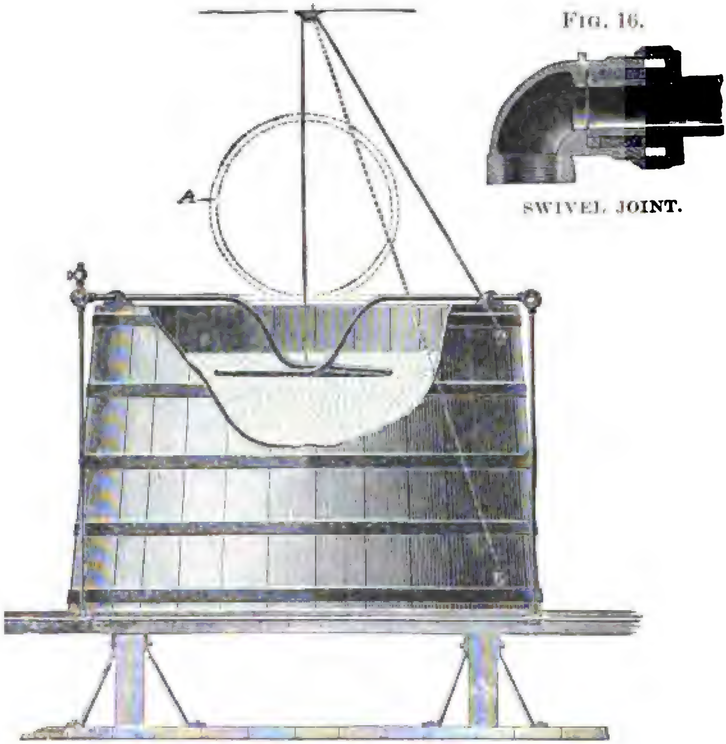


FIG. 16.

SWIVEL JOINT.

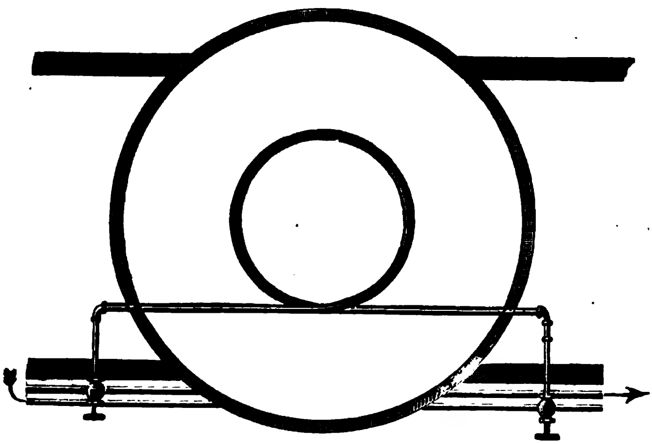
ELEVATION.—IN POSITION—PORTION OF TANK REMOVED.
Position when swung out of use shown by dotted lines.

which has been cooled in a tank or cooler in the same way as brine is cooled in the indirect brine system. In fact the arrangement is precisely after the plan of the indirect brine system, with the substitution of fresh water for brine for the secondary medium, including the pump for maintaining cir-

culation. An automatic regulator is arranged to hold the temperature within prescribed limits. A plan of an automatic outfit is shown in the illustration, Fig. 15. In the case shown each or any number of tubs can be shut off or regulated at will. The pressure and amount of cooling water are under automatic control of the regulator and self-acting pump and need no attention, whether one tub or many are in use.

Another method is to have the attemperator supplied by gravity from a cold water tank, with necessary cooling coils placed above the uppermost fermenting room. In order to control automatically the quantity of water pumped in accordance with the demand, a long stand-pipe receives the water in its passage through the attemperator. According to the

FIG. 18.



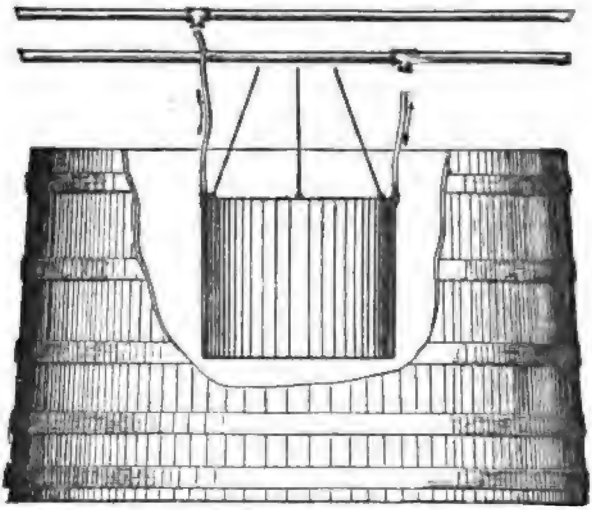
BOYLE'S ATTEMPERATOR.
Plan.—In position.

amount of water used the height rises and falls in this pipe, thus varying the pressure exerted on a rubber diaphragm which controls the steam throttle of the pump. Thus the amount of water returned to the tank by the pump is made to correspond to the amount of water used.

An attemperator arranged with swivel joint so that it can be swung up out of the vat is shown in Figs. 16, 17 and 18.

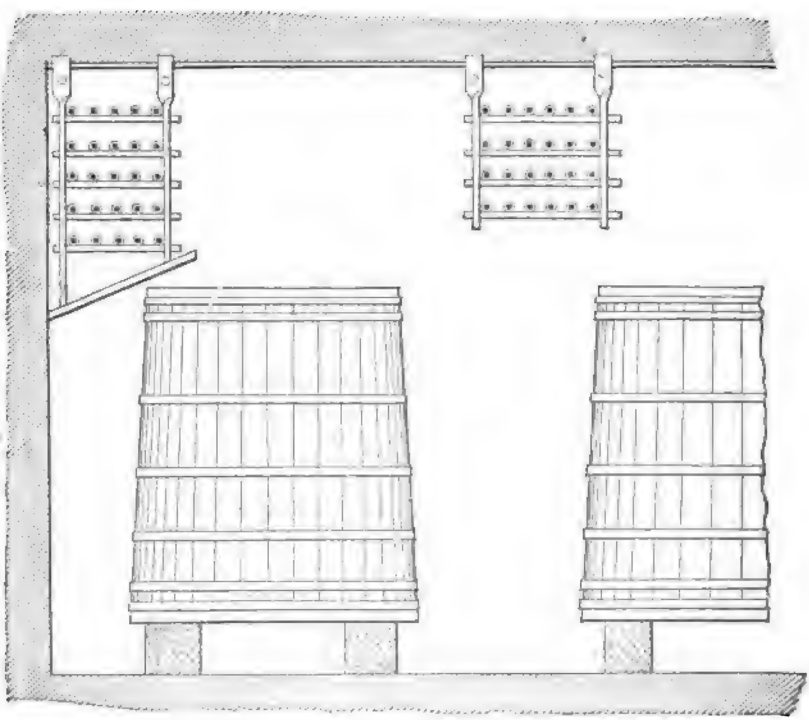
3

Fig. 19.



CYLINDRICAL ATTEMPERATOR.
ATTEMPERATOR IN POSITION—HAS PULLEY FOR RAISING OR LOWERING.

Fig. 20.



FERMENTING ROOM COOLING.

An example of the hollow cylindrical type is shown in Fig. 19. Flexible connections for the water are used with this type.

In Fig. 20 is shown an arrangement of pipe work in fermenting room, coils being suspended from iron floor beams and located in passageways and at side of room, thus preventing drip into tubs, and affording free access to the tubs.

THE ICE SKATING RINK.

The production of ice independent of Jack Frost once established, the special adaptation of the art to the production of ice for skating purposes appears as one of the possibilities. All that is wanted is a combination of enterprise and capital.

One method of carrying out the idea is to freeze water flooded over the refrigerating pipes arranged close to the floor. The ice that is formed is clear and transparent, the pipes below being readily seen through it. The foundation ice is formed once for the season. The surface cut up by the skating is re-formed nightly. When it has grown thicker than desired, it is planed down. This method may be considered as a special application of the plate system of making ice. This is the method shown in the illustration, Fig. 21. This is the method most generally followed.

An ingenious method of obtaining an ice surface of uniform thickness, smooth and homogeneous, and with some degree of elasticity, is one which may be classed as a special application of the can system of making ice. What corresponds to the can consists of a large shallow tray with a thin steel bottom, this tray covering the area over which it is desired to form the ice. This tray, as in the can system generally, contains the water to be frozen, in this case being quite shallow. Beneath the tray is a stratum of flowing brine, which is reduced in temperature according to the usual method. The ice formed by this method is a clever artificial reproduction of natural ice as first formed on the surface of a pond.

Fig. 21.

SKATING RINK. VIEW SHOWING PIPES BEFORE FLOODING. (De La Vergne.)

REFRIGERATION ON SHIP-BOARD.

One of the most useful applications of refrigerating machinery is on ship-board. This application may be limited to simply the preservation of ship-stores and provisions on board passenger or cargo steamers, pleasure yachts or men-of-war or it may be depended upon for the preservation of a whole cargo of fresh meat or fruit.

Any of the various successful methods of refrigeration may be employed on ship-board, except that with ammonia the direct expansion system is not used. Either the indirect brine system or indirect air system are used instead.

THE COMPRESSED AIR SYSTEM.

In the earliest efforts at refrigeration on ship-board the compressed air system was utilized. The method followed was to exhaust the refrigerated air directly through suitable ducts into the chambers to be refrigerated and draw the supply of fresh charge for the air-compressor from the same chambers. Considerable trouble was experienced from the accumulation of snow in the cold-air ducts and the expansion cylinder, due to the freezing of the moisture drawn in with the air.

By means of occasional thawing out and removal of snow and vigilant oversight of operative features these plants were maintained in successful operation and gave way only to something better. As apparatus with other refrigerating mediums produced results without the troubles that have been mentioned with better efficiency and more compact apparatus, the compressed air system for general cargo service in due time became obsolete.

There are features of the compressed air system that appeal to favor. One of these is the lack of necessity of carrying a special stock of refrigerant. This especially applies in the case of a man-of-war. Then there is the feature of harmlessness of the medium. The trouble from snow can be largely eliminated by holding the air confined and keeping the same supply in continuous circulation, replenishing losses with air that has been freed from moisture, and the efficiency can be

improved by using air at several times normal density. In one case the minimum pressure is five atmospheres.

With these improvements, there is still a field for the air machine for preserving ship stores, especially on merchant vessels, men-of-war and pleasure yachts.

AMMONIA COMPRESSION SYSTEM.

The good points of the indirect brine and air systems as employed for land service apply equally well at sea. In either case space is required for the accommodation of the circulating system consisting of brine pipes for the one and air ducts in the other, which space is hard to find in vessels built for ordinary service. In recent years excellent vessels have been constructed especially adapted to the transportation of refrigerated goods, showing that naval engineers have succeeded in meeting the requirements of the situation.

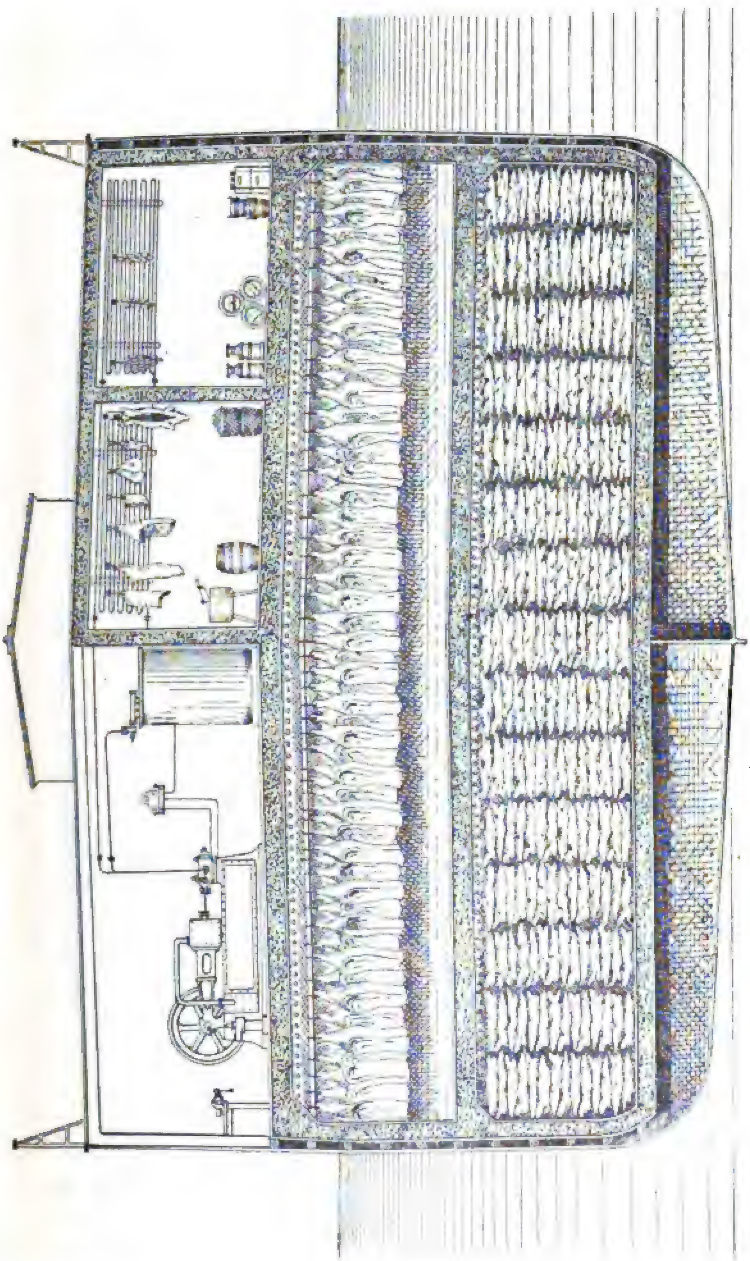
The objection to the use of direct expansion with ammonia may be readily surmised to be danger of leakage. While the trouble from this source has been really at a low point, the liability of trouble of this kind from a network of piping with high pressure on shipboard is too serious to be risked. At the same time the direct system may be used to a limited extent without particular danger for cooling the ship's stores and provision chambers. This is especially convenient where the indirect air system is used for general cargo.

In regard to danger to life and damage to cargo, while carbonic anhydride will not sustain life, there is no serious likelihood of loss of life due to leakage. As far as the effect on cargo is concerned, there is no possibility of injury.

As either the indirect brine or the indirect air system is generally employed, there would be no special features to be noted in regard to the refrigerated chambers due to the use of carbonic anhydride as the refrigerant.

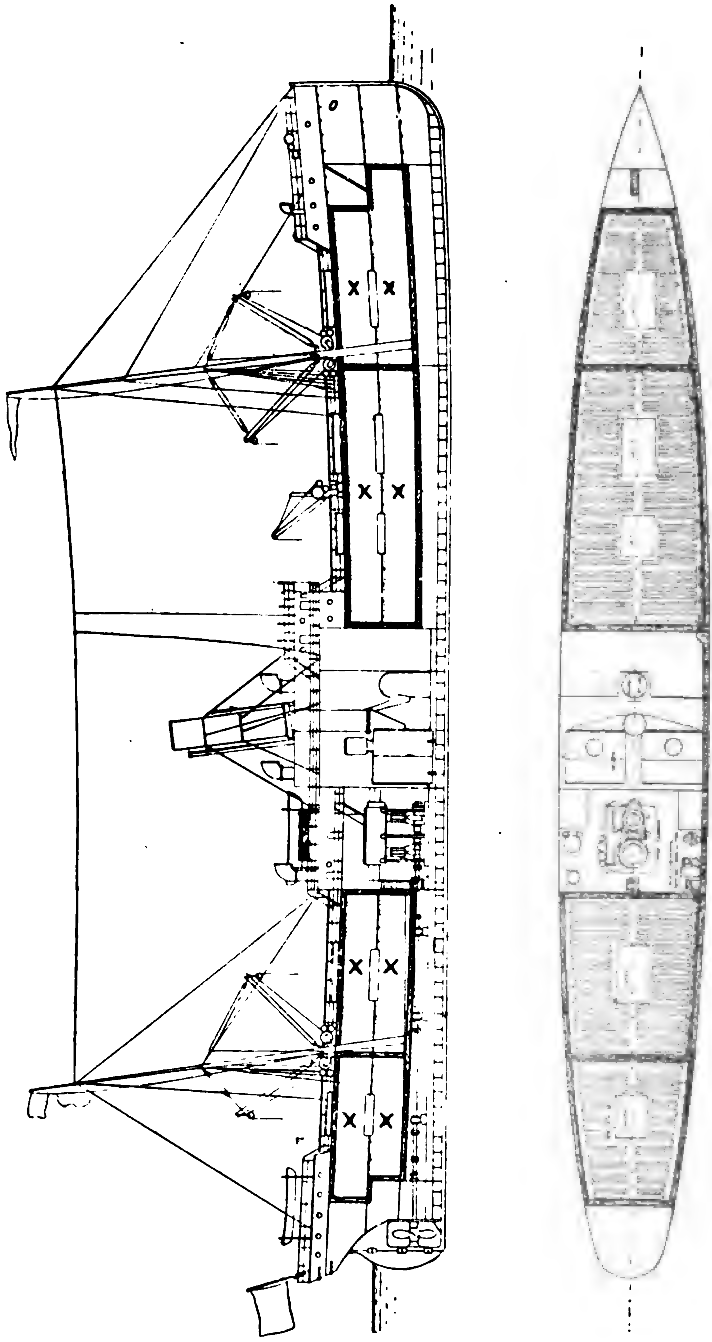
The illustrations given herewith show sections of a modern steamship equipped for refrigeration with carbonic anhydride system with indirect brine circulation. Fig. 22 shows a section of a transatlantic steamer used exclusively for the trans-

FIG. 22.



VERTICAL SECTION THROUGH A TRANSATLANTIC STEAMER, EQUIPPED WITH MODERN CARBONIC ANHYDRIDE REFRIGERATING MACHINERY, AND USED EXCLUSIVELY FOR THE TRANSPORTATION OF REFRIGERATED MEATS.

FIG. 23.



REFRIGERATED STEAMER FOR TRANSPORT OF BUTTER AND BACON. REFRIGERATED HOLDS.

portation of refrigerated meats. Fig. 23 shows longitudinal sections, horizontal and vertical, of a Danish butter export steamer.

PIPE LINE REFRIGERATION.

The use of pipe lines for the transmission and distribution of water and gas is of quite long standing. The use of wire for the distribution of electric light and power, though more recent, is nevertheless familiar to the general public. The central station for the distribution of light, heat and power is commonplace. A central station for the distribution of refrigeration, however, may be set down as something of a novelty. A little thoughtful consideration of the subject will, nevertheless, promptly reveal the feasibility of the idea, while all doubts will be removed by observation of the scheme in operation. We are destined to hear more about this idea in the future.

PRACTICAL FEATURES.

Some of the difficulties and obstacles in the way of successfully maintaining a general system of refrigeration from a central station are similar to those encountered generally in central station work, and others are peculiar to the subject of refrigeration.

One of the principal problems presented is that of the successful handling of a variable load. One way, not particularly scientific or economical is to have sufficient machinery available to handle the maximum load and to vary the number of machines in operation or the output in accordance with the load or demand. This arrangement is also uncertain and inconvenient, and will hardly meet the emergency of a sudden change in load, such as is liable to occur at any time without warning.

The ideal system will be the one that will enable the extreme variations in load to be maintained by machinery of about average capacity of load instead of maximum.

The systems that have been tried to a greater or less extent are the indirect brine system and the absorption system operating with direct expansion of ammonia.

THE BRINE SYSTEM.

Distribution by the brine system requires the brine piping to be insulated outside of the refrigerating chamber. This involves considerable care as well as cost in installation. Whether or not this is the proper system for a general distribution system has not as yet been demonstrated. What has been done in this line has been confined to the supplying of a large market district from the power station of a large cold storage company, the distribution being mostly for the company's own use or for apartments let out to tenants. As a distance of 2,000 feet from the point of distribution has been successfully covered, without intimation that the limit has been reached, it is evident that it is possible to cover a considerable area of territory with this system. The insulation feature is the draw-back, while the favorable feature is the low pressure in the pipe system.

A pipe that has been used with success is cast iron bell and and spigot pipe, with joints made in special manner. The pipes are laid in boxes made of creosoted or "kyanized" plank, the boxes being filled with a mixture of pitch and cork. The good results obtained in operation speak well for this form of piping and insulation, as there can be no question that it is upon these features that the success depends.

ABSORPTION SYSTEM WITH DIRECT EXPANSION.

The application of the direct expansion system to pipe line refrigeration involves the use of a suitable expansion or regulating valve on the premises of the customer. In order to obtain the greatest friction head possible and at the same time be able to produce low temperatures at distant points it is desirable to have low back pressure at the station. This condition implies low density of vapor or more likely superheated gas in the return mains. As the absorption system is best adapted to operate under these conditions, this system is generally used for the purpose. Furthermore this system is inherently adapted to operate under varying conditions of load. In case the ammonia vapor happens to come along slowly it

is not a serious matter to have the weak liquor wait for it. It is quite a different matter to have a compressor operating at full speed without doing any appreciable work.

In practice the inherent flexibility of the absorption system is materially improved upon by the adoption of suitable storage tanks or reservoirs. Three of these are used to produce the ideal system. One of these is for holding liquid anhydrous ammonia. This corresponds to the liquid receiver in common use with the various systems, including the compression system. The second reservoir is for the strong aqua ammonia and the third for the weak aqua ammonia.

A feature largely responsible for the success of the direct system is the use of an auxiliary main, called the vacuum line, in parallel with the regular supply and return mains. The vacuum line is connected at the service connection with the liquid line, the return line and the expansion coil. By means of this arrangement, with suitable valves, repairs may be made on any coil or section of mains without disturbing the rest of the system, the vacuum line being used to exhaust the ammonia from the coils or section of piping or as a cross-connection or temporary main while a section is being repaired.

In order to allow for expansion and contraction due to variations in temperature expansion joints are required in the piping. These pipes are in some cases encased in a protecting covering, though insulation is not always required. The refrigerant is maintained in a liquid condition up to the expansion valve by the condenser pressure. The expansion valve is adjusted so as to allow complete vaporization in the coils of the refrigerator, so that the vapor enters the return mains at slight superheat though at low temperature, so that there would be some advantage in insulation of the return mains.

ECONOMIC CONSIDERATIONS.

A large consumer can afford to have his own refrigerating plant. This a small consumer cannot do. A similar statement might apply to electric lighting and to other industries. The central station is a necessity to the small consumer. It may also be a help to a large consumer.

The small consumer can afford to pay a good price to the central station for something he cannot obtain in any other way. The necessity for exorbitant rates, however, does not exist in the supply from the central station, on account of the great economy obtainable by production on a large scale.

Furthermore, there is economy in the actual refrigeration as against the utilization of ice, on account of the avoidance of waste in refrigerating material. A reference to the subject of relative rating of machines for refrigerating and ice making will help on this point. An amount of refrigerating equivalent to that produced by the expansion coil in the refrigerated chamber, rated according to the usual methods in tons of ice melting capacity, would be capable of producing only from fifty to sixty per cent. of that amount of ice.

The question of delivery arises in either case. In the central station system there is a network of piping to maintain. With the ordinary methods there is a system of delivery wagons to maintain. The delivery of ice is one of the largest factors in the cost, especially to the smaller consumer.

While the stage has not been reached for supplying household refrigerators, the fact that good-sized plants that have been in operation for years have been displaced by central station supply shows that the system of pipe line refrigeration has merits in the line of economy.

With the record of the progress that has been already made in mind, we may yet hope for connecting our ice boxes and refrigerating systems in our homes with the central station. Then will have been reached the acme of convenience and comfort through our ability to obtain refrigeration as well as water, light and heat by the simple turning of a handle or pressing a button.

CHAPTER V.

ICE-MAKING.

THE modern system of refrigeration owes its origin to the development of the process of artificial ice-making. The ice machine came first and the idea of producing the cold at the place where it is wanted followed.

Much time and space could be devoted to a consideration of the early history of the art and the vicissitudes through which it has passed to reach the stage of the present day. Suffice it to say as regards this feature that it has long emerged from the experimental stage and has settled down to a routine business. There will be changes and improvements with the advance of time, but these may be expected to follow along the channels already marked out. Changes of a radical or revolutionary character, always a possibility in this startling age, are creating very little disturbance along this line of work.

There are two general methods of ice-making distinguished by the relative locations of the freezing mediums and the water to be frozen: one in which the water to be frozen is outside of the freezing medium, and the other in which the freezing medium surrounds the water.

The representative of the first class is known as the plate system. The other is known as the can system. In the plate system the ice is formed on the outer walls of a hollow plate, adapted for the circulation of the refrigerating medium in the interior space. In the can system the ice is frozen in cans immersed in a freezing mixture made of brine.

Other systems are advocated and used to some extent such as the cell system in which the ice is formed in cells formed by subdivision of a large tank and the block system in which a large body of water is frozen in a tank and the ice cut into blocks. All of these possess more or less merit. The essential

principles may be obtained, however, from a consideration of the two systems mentioned.

HYGIENIC AND TRANSPARENT ICE.

Hygienic ice would be such as would be wholesome or sanitary, or non-injurious to health if taken internally into the system. Ice made from potable water by natural processes would be hygienic. With doubts as to the wholesomeness of the water, there would be doubts as to the quality of the ice. Ice may, however, be hygienic and still not be transparent. In other words it is not necessary for ice to be clear, crystal ice to be hygienic. As this fact is not generally understood, the market demand is for the clear and crystal ice, with the understanding that it is hygienic. This demand has been met successfully, although to meet the demand for transparent ice has involved considerable ingenuity and elaborateness of method, all of which add to the cost of the product. The fact is that the principal cause of opaqueness is the presence of air in the water. Various elaborate schemes have been devised for the removal of this air, especially with the can system, involving some method of agitating the water during freezing. This was accomplished by a mechanical agitator or paddle in the can, operated from a shaft or by admitting air under pressure at the bottom of the can by means of a perforated pipe, thus producing a circulation. Towards the end of the process in either of these methods the special devices had to be removed from the can to prevent being frozen into the block of ice. Another method was to agitate the whole can during the freezing process. The final methods of to-day for use on a scale is for the plate system to agitate the water by means of jets of compressed air, admitted at the bottom of the freezing cell and to use water in the can system from which the air has been removed by distilling, in which process, of course, the water is at the same time made wholesome, so that ice made by this process ought to be unquestionably hygienic.

FIG. 24.

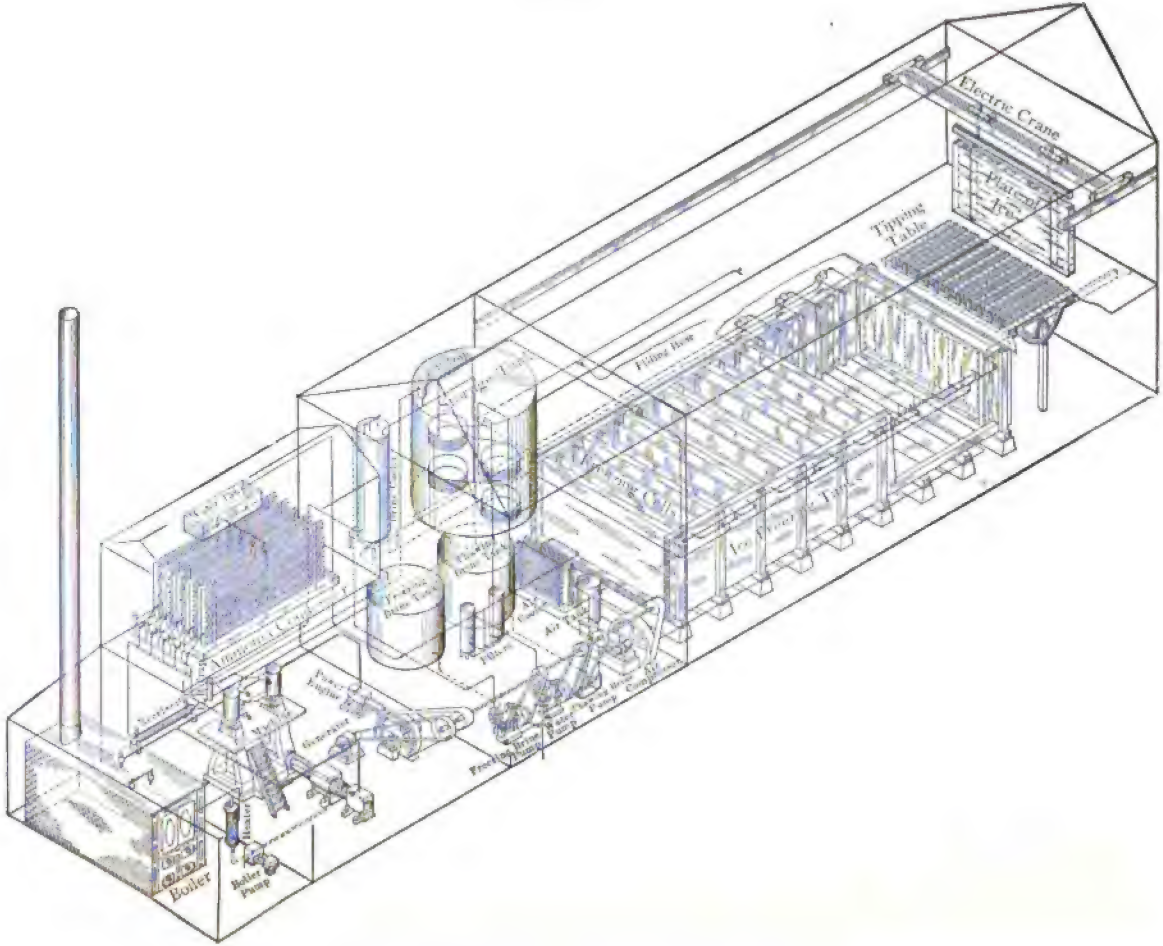


PLATE ICE-MAKING PLANT (ISOMETRIC INTERIOR VIEW).

(Opposite page 4

PLATE ICE-MAKING.

The plate ice-making process is a good imitation of the natural process of making ice on rivers and ponds, except that the ice cake is formed against a vertical plate instead of horizontally. Similarly to the natural process, as the ice forms, particles of foreign matter in suspension in the water are rejected to the residual unfrozen portion. This is drawn off at the termination of the freezing process. Air particles are removed by agitation by compressed air jets admitted at the bottom. The ice is made in large blocks which require cutting up into smaller blocks of marketable size. One standard size is 16 feet long by 8 feet deep and 12 inches thick, producing after harvesting a net result of about 3 tons, allowing about 20 per cent. for losses.

In order to handle these large blocks of ice, powerful hoisting and transporting mechanism is required. For this purpose a modern traveling crane is employed, the ice being supported by chains passing around the same or by means of wrought iron rods frozen into the ice. For convenience in handling, the ice is delivered by the crane to a tilting table, on which it is brought to a horizontal position and cut up to the desired size by suitable saws. An isometric view of a complete plate ice-making plant is shown in Fig. 24.

The freezing plate is made up with sides of sheet metal, enclosing some arrangement for the circulation of the freezing medium as well as means for releasing the frozen cake from the plate. A number of different plans are followed in regard to the internal arrangements of the freezing plate. Either the direct or indirect brine system may be employed.

One plan is to use the entire space between the plates for the circulation of brine, the releasing of the plate being affected by the use of warm brine.

It is more common, however, to have the plates of sheet metal serve as a facing for a coil of pipe for the circulation of the cooling medium. With direct expansion the release of the plate may be affected by the circulation of warm gas from the condenser in the freezing coil or by the circulation of hot gas,

or hot water or brine in a special coil for the purpose. With the direct expansion there is some unevenness of freezing due to drop in temperatures along the length of the expansion coil from the regulating valve to the compressor. The method would in general have the advantage of economy of power, which is quite an item for any ice plant.

The usual good results obtained with the indirect brine system, apply also to the making of plate ice.

A typical method of constructing the freezing tank and cells is to use one large tank, subdivided into cells two or three feet wide by the freezing plates. The number of compartments or cells is selected to allow for drawing the ice, cleaning and refilling of one each twenty-four hours. The time of freezing would be accordingly about one week, for a thickness of one foot.

In the mechanical operations of harvesting there is ample opportunity for utilizing up-to-date labor-saving devices, such as hoisting and traveling cranes; automatic machinery for sawing ice into blocks; and power ice handlers and conveyors.

CAN ICE-MAKING.

Although the can process of ice-making as carried out in accordance with the prevailing methods involves more care in producing the same quality ice as the plate process, it is nevertheless the fact that probably two-thirds to three-fourths of the artificial ice is made by this process.

The plan followed in general is to form the ice in moulds or cans, the lower portions of which are arranged to be surrounded by brine at freezing temperature.

Necessary features are a freezing tank, with freezing medium, ice-moulds or cans, and arrangements for lifting cans with ice out of tank, removing ice from cans, re-filling cans and replacing in tank.

Special features would include means and methods employed with a view to increasing the economy and facilitating the handling and storing of the product. These involve the shape and size of the moulds, dimensions and construction of tank,

means of reducing temperature of brine for freezing, means for improving the transfer of heat from the moulds to the brine, and labor-saving devices for use in the operations of harvesting the ice and re-filling cans. Of most importance of all are the means provided for obtaining water free from foreign matter, especially such as would prevent the production of ice that would be wholesome and clear.

As there is some choice of method in carrying out these various features, and furthermore as changes are more or less involved, a change in one feature necessitating a change somewhere else, there is more or less variety in details for different plants, even for plants of good size and giving good results.

Under the circumstances it may suffice to call attention to methods that are in use with good success, with some reference to other methods that have been used to some extent to attain the same ends.

Brine is made of calcium chloride, of as great a density as possible without danger of freezing.

Freezing tank is made of steel, with suitable insulation on outside, in accordance with one of the recognized standard plans. Covers are somewhat of a weak feature. They are generally made of wood, without special insulation, the insulation qualities being sacrificed in favor of handling and durability.

Sodium chloride brine and wooden tanks were in common use for a long period, and are still much used. The reasons for the coming into favor of calcium chloride are further enlarged upon in the following pages in the chapter on brine.

STANDARD CANS.

Action along the line of standardization of ice cans was taken at a meeting of ice and refrigerating machine builders held at Cincinnati, April 3, 1903, with results as given below:

Cans made of No. 16 steel are to have sides turned over at top and bottom.

Cans made of No. 14 steel are to have sides brought up flush at top and bottom.

All cans are to have one-inch inverted bottom.

Bands are to be welded and galvanized with $\frac{5}{8}''$ hole for lifting hook, the bottom of hole $\frac{15}{16}''$ from top of band.

DETAILS OF CANS.

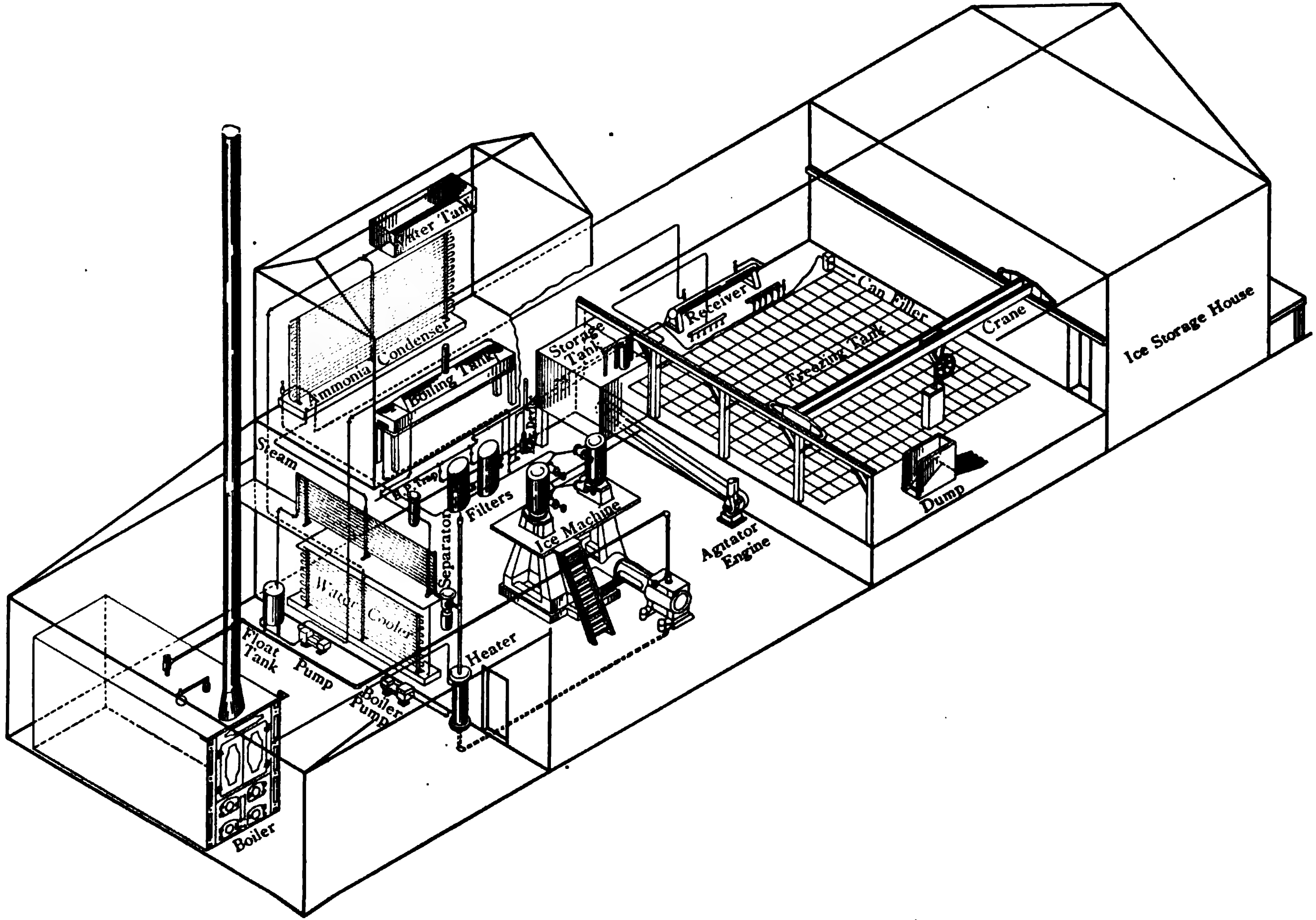
Capacity. lbs.	Dimensions in Inches.					Material. U. S. Gauge.
	Top.	Bottom.	Depth.		Band.	
			Inside.	Outside.		
50	8 x 8	7½ x 7½	31	32	1½ x ¼	No. 16 steel.
100	8 x 16	7¼ x 15¼	31	32	2 x ¼	" "
200	11½ x 22½	10½ x 21½	31	32	2 x ¼	" "
300	11½ x 22½	10½ x 21½	44	45	2 x ¼	" "
400	11½ x 22½	10½ x 21½	57	58	2 x ¼	No. 14 steel.

Brine refrigeration is to be effected in a brine cooler, outside of the freezing tank. This method does not correspond with the one in most common use, in which the brine is reduced in temperature by means of expansion coils installed submerged in the brine in the freezing tank. The latter method was generally preferable to separate refrigeration of the brine with the old-fashioned brine tank, but cannot equal the results obtained in the modern double-pipe brine cooler.

Rate of freezing, or what amounts to the same thing, rate of transfer of heat from water to be frozen to brine, is facilitated by agitation of brine and keeping the same in circulation. With separate cooling of brine this result is readily attained by a proper location of inlet and outlet pipes for brine, which, of course, is maintained in circulation by pumps. With the evaporating coils within the freezing tanks the brine is kept in motion by means of propellers or circulating pumps.

For harvesting, use pneumatic or electric hoist mounted on a traveling crane, arranged to deliver to an automatic thaw-

FIG. 25.



CAN ICE-MAKING PLANT (ISOMETRIC INTERIOR VIEW).

(Opposite page 51.)

ing and dumping device. In this device the water should be automatically turned on when it is wanted for releasing the ice from the can and shut off again when the ice has slid out of the can and water is consequently no longer needed.

This idea may be further elaborated by arranging to have several cans harvested at a time or as many as a whole row.

The filling of cans may be arranged by means of an automatic can-filler which is arranged to fill from the bottom, so as to avoid as much as possible the entraining of air and which is arranged to shut off the water when the proper depth is reached.

The apparatus that has been mentioned would be sufficient to produce ice, provided simply that the cans were filled with water. As we are considering in the present case what will be required to produce the best product, it is necessary to add elaborate water-distilling and -purifying apparatus. Assumed that the plant is operated from a steam engine, there is exhaust steam available for the larger part of the supply needed. Surplus can be added directly from the boiler. This latter would not call for much complication. It is the steam that has been used in the engine, after having become laden with lubricating oil in the cylinder that does require special treatment. Briefly described, this consists of the following:

Oil separation, in the oil separator; condensation in the steam condenser; re-boiling to drive out air and remaining oil, in the re-boiler; skimming in the skimmer, to remove scum and impurities by running off at top, these latter two processes being generally combined; filtration by passing through suitable filters of water drawn from the bottom of the skimmer; fore-cooling in the cold-water storage-tank, preliminary to freezing.

Between the steam separator and the steam condenser it is a point in economy to utilize as much heat as possible in the steam to be condensed in a heater for heating feed-water for the boiler.

An isometric view of a complete can ice-making plant is shown in Fig. 25.

OPERATIVE FEATURES AND COST.

In general a plate plant for a given capacity costs nearly twice as much to install as a can plant, while the yield for a given amount of power is perhaps 30 per cent. to 40 per cent. greater. With gas or water power or cheap electric power available, and water suitable for producing merchantable ice without distillation, the plate system would be the proper one to use. With steam power, while the plate plant would unquestionably hold its own in point of economy, the advantages would not be so great as to lead to a general adoption of the plate system, especially in view of the higher cost of installation.

The extra cost of the plate plant covers in large part labor-saving devices, which pay for themselves in the normal conditions of operation. The plate plant will produce a larger output of reliable quality with less skillful oversight and management than a can plant. Neglect in a can plant may result in the production of a bad run that would lead to complaints and a damaged reputation.

STORAGE.

A feature in favor of the plate system is facility of storage. Can ice does not lend itself to economical storage on account of the wedge shape of the cake and for the same reason exposes relatively much larger surfaces to contact with the air. Therefore, it is not policy to store can ice in quantities for long periods.

Plate ice on the other hand can be cut in blocks for economical storage, like natural ice, and can be stored practically indefinitely. The result of this is that a small-sized plate plant operated steadily throughout the greater part of the year, and storing the product for the busy season, may answer to serve a field that would require a can plant of much larger capacity operated to meet the maximum demand as it arises. Accordingly the relative cost of installation of a plate plant and a can plant on this basis would be more nearly in favor of the plate plant.

Figs. 26–27.

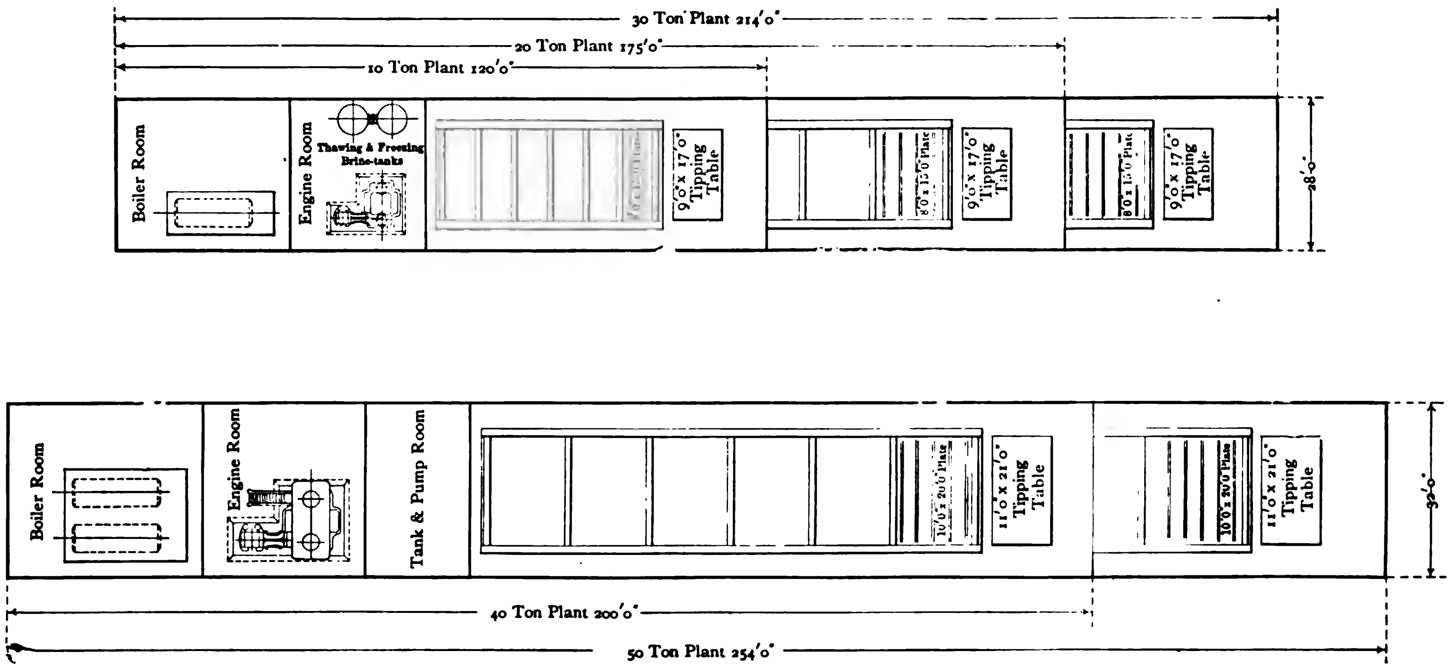
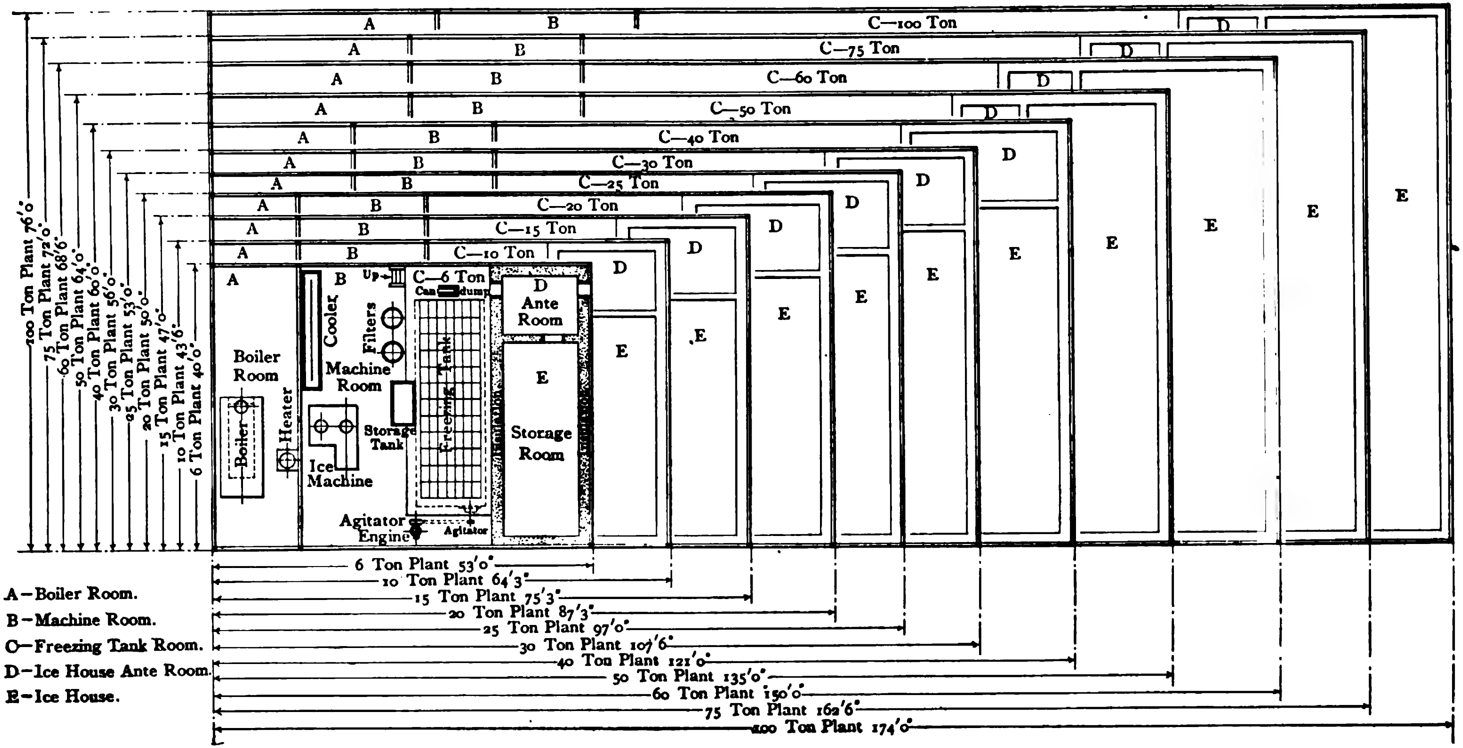


PLATE ICE-MAKING PLANT (GROUND SPACE CHARTS).

(Opposite page 53.)

Fig. 28.



CAN ICE-MAKING PLANT (GROUND SPACE CHART).

(Opposite page 58.)

Can ice requires refrigerated rooms for storage, whereas plate ice can be stored in every way like natural ice. Nevertheless, present practice seems to favor refrigerated storage rooms in any case. Rooms are maintained at about 26° F. by means of either direct expansion or brine coils. With 18° F. brine, there would be required about 50 square feet of pipe surface for 1000 cubic feet of storage space, while with direct expansion there would be required about two-thirds to three-fourths of this amount.

SPACE REQUIREMENTS.

Ground space charts are shown in Figs. 26 and 27 for plate ice-making plant, exclusive of storage room, and in Fig. 28 for can ice-making plant complete. It will be noted that even for the conditions given the ground area for the plate plant is nearly as great as for the can plant of corresponding size, being close to 200 square feet per ton.

OUTPUT.

The production for a plate plant will range from 10 tons to 14 tons of ice per ton of coal, while for a can plant the range will be from 6 to 7½ tons.

COST.

The cost is an interesting and important feature and as in other lines may be varied considerably by local conditions and the ideas of the promoter. Accordingly data on this line are to be regarded merely as approximations, representing what may be expected for average conditions.

A few data on cost are given herewith, sufficient to give a general idea of this phase of the subject.

COST OF INSTALLATION.

An estimate as to cost of installation as given by a prominent manufacturer is as follows:

Can system	$5.50 per ton.
Block system	6.50 per ton.
Plate system with direct expansion plates	8.00 per ton.
Plate system with brine plates	10.00 per ton.

COST OF OPERATION.

The operating expenses of an ice-making plant are made up of salary of superintendent and engineers, wages of firemen, tankmen, and other labor, cost of fuel, light, oil and waste, slight loss of chemicals and sundry small repairs.

The amount of salary paid the superintendent and engineers is of course dependent upon the size of the plant. Firemen, tankmen and other labor are paid $1.25 to $1.75 per day of twelve hours.

The cost of fuel is of course dependent upon the available market. The consumption of steam by a single cylinder, non-condensing Corliss engine is 26 pounds per 1 H. P. per hour. Under summer conditions with condensing water at 70 degrees, and carrying 190 pounds condenser pressure and 15 pounds suction pressure, about 2¼ H. P. is required to produce one ton of ice. There will, therefore, be required for the engine operating the ammonia compressors approximately 58½ pounds of steam, or, figuring the evaporative power of coal at eight pounds of water evaporated per pound of coal burned, 7¼ pounds of coal per ton of ice-making capacity per hour. The balance of the plant will require approximately 12 pounds of steam or 1½ pounds of coal per hour, making a total of 8¾ pounds of coal per ton of ice-making capacity per hour, or 210 pounds per day.

If, however, the ice is made from distilled water, as with the "can system," the amount of water evaporated is about 20 per cent. greater than the weight of ice obtained. This excess represents steam escaping to the atmosphere; also the loss in skimming and loss by melting of the ice in extracting it from the cans. The total steam consumed per ton of ice-making capacity per day is, therefore, 2,400 pounds, this requiring a consumption of 300 pounds of coal.

A table, giving approximate cost of operating ice factories is given herewith.

APPROXIMATE COST OF ICE-MAKING.

Tons Ice Per Day.	Engineers $2.50 to $5.00 Per Day.	Oilers $2.00 Per Day.	Firemen $1.50 to $1.75 Per Day.	Tankmen and Laborers $1.25 to $1.50 Per Day.	Coal $2.00 Per Ton.	Oil, Waste, Light and Sundries.	Daily Operating Expenses.	Cost of Ice Per Ton.
10	2 at $4.50	....	....	2 at $3.00	3,600 at $3.60	$1.50	$12.60	$1.26
20	2 at 5.00	....	2 at $3.00	2 at 3.00	6,600 at 6.60	2.00	19.60	.98
25	2 at 5.25	....	2 at 3.00	2 at 3.00	8,000 at 8.00	2.50	21.75	.87
30	2 at 5.50	....	2 at 3.00	2 at 3.00	9,300 at 9.30	3.00	23.80	.79
40	2 at 6.00	....	2 at 3.00	3 at 4.50	12,300 at 12.30	3.50	29.30	.76
60	3 at 9.00	1 at $2.00	3 at 4.50	3 at 4.50	18,000 at 18.00	4.00	42.00	.70
75	3 at 10.00	1 at 2.00	3 at 4.50	4 at 6.00	22,000 at 22.00	4.50	49.00	.65⅓
100	3 at 11.00	1 at 2.00	4 at 6.00	6 at 9.00	28,500 at 28.50	5.00	61.50	.61½
120	3 at 11.50	1 at 2.00	4 at 6.00	6 at 9.00	34,000 at 34.00	5.00	67.50	.56¼

CHAPTER VI.

PRACTICAL PRIMARY REFRIGERATING MEDIUMS.

THERE can be no question as to the importance of the role played by the primary refrigerating medium in a refrigerating plant. Accordingly, it ought to be of interest to consider the qualifications that determine the use of such a medium. In doing this it will be of assistance to bear in mind that the function of a refrigerating medium is to store up heat at a low temperature, and discharge it at a high temperature, with the assistance of mechanical energy. Accordingly one of the essential qualifications of a refrigerant is the ability to absorb a large amount of heat at the lower temperature which it can deliver at the higher temperature. Further than this, there must be reasonable and practical limitations to the working pressures and size of apparatus.

In seeking a medium to meet these requirements, recognition is taken of the physical property of matter in general that in changing the physical state, as from a liquid to a vapor, an appreciable amount of heat is stored up as latent heat without change in temperature, which heat is again given up when the liquid condition is again resumed. Accordingly, a suitable substance is one that can be changed alternately from a vapor to a liquid and back again within the given range in temperature and at the same time has a high value for the so-called heat of vaporization.

Briefly stated, heat of vaporization is drawn in at the lower temperature and heat of liquefaction is delivered at the higher temperature.

Another feature of importance is the fact that before the liquid formed at the higher temperature can vaporize at the lower temperature the liquid itself must be lowered in temperature to correspond to this lower temperature. The heat re-

quired to do this is supplied by the refrigerant itself, at the expense of its ability to take up heat at the lower temperature. This means simply that the ability to do refrigerating duty is reduced by an amount depending upon the amount of drop in temperature for the liquid and the specific heat of the liquid. Accordingly, another desirable qualification is low specific heat for the liquid.

We have now stated the principal requirements in regard to a refrigerant and are accordingly in a position to pass on the merits of the refrigerating mediums in common use from the theoretical standpoint. These mediums are ammonia (NH_3), sulphur di-oxide (SO_2) and carbon di-oxide (CO_2).

CRITICAL DATA:—In order to take advantage of heat of liquefaction it is necessary to operate below the critical temperature.

The critical temperature is the point in temperature to which a gas must be reduced before it can be liquefied, even with exceedingly great pressure.

The critical pressure is the pressure that is required to produce liquefaction at the critical temperature.

There is considerable difference in the values for the critical data for the substances under consideration, as will be noted from the table given herewith.

CRITICAL DATA.

Substance.	Critical Temperature, Degrees F.	Critical Pressure Atmospheres.
NH_3	266°	115
SO_2	313°	81
	311.72	79
CO_2	88°	75
	87.8°	77
	87.7°	74

One atmosphere corresponds to a pressure of 14.7 pounds per square inch.

Whether or not liquefaction takes place depends upon the value for critical temperature and the value for temperature to which the medium is reduced by means of the cooling water before it is admitted to the expansion valve.

This value for temperature will depend upon whether a simple condenser is used or provision is made for liquid fore-cooling after condensation has taken place. We will assume a value for each of these cases, respectively 85° F. and 73° F.

An inspection of the table of values for critical data shows that for the temperatures given liquefaction will take place for all of the substances listed for the temperatures under consideration. It will be noted, however, that the temperatures given are not far from the critical temperature for CO_2. As a matter of fact the critical temperature for this substance is very often exceeded, as in the tropics, without refrigeration being actually interrupted, with however, a loss in efficiency of 50 per cent. in some cases.

HEAT OF VAPORIZATION:—As the refrigerating effect is to a large extent measured by the value for latent heat of vaporization, it is important to determine this feature. As this has different values for different temperatures, the value wanted is that corresponding to the particular temperature at which vaporization takes place. The temperature of vaporization corresponds to the lowest temperature reached in the expansion or evaporating coils and is accordingly the lowest temperature reached in any part of the system. This temperature we will assume in the given case to be 2° F. Data in regard to heat of vaporization for different temperatures and corresponding pressures are found in tables giving the properties of the different mediums. Data in regard to these points for the temperatures that have been named are reproduced herewith.

HEAT OF VAPORIZATION AND PRESSURE.

AMMONIA.

TEMPERATURE, DEG. F.	HEAT OF VAPORIZATION, B. T. U.	PRESSURE, ABSOLUTE, POUNDS PER SQUARE INCH.
85°	501.81	167.88
73°	509.58	136.31
2°	554.27	31.84

SULPHUR DIOXIDE.

85°	148.5	65.3
73°	152.5	56.8
2°	170.8	11.1

CARBON DIOXIDE.

85°	29.3	1036
73°	55.7	897
2°	118.2	322

An inspection of the table will show that on this score alone judgment would be decidedly in favor of ammonia.

The table shows also enormous differences in pressures for the different mediums. The fact that the three mediums are actually in use shows that they are within practical limits.

LIQUID COOLING:—From the specific heat of the liquid and the range in temperature through which the liquid is depended upon to cool itself is determined the loss in refrigeration effect due to this cooling of the liquid. The range in temperature is a feature determined by the prevailing conditions of operation. For this we have assumed the two values respectively 85—2 = 83° F. and 73—2 = 71° F.

The specific heat of the liquid is an inherent property of the refrigerating medium which can be determined by experiment only. Unfortunately there is not very close agreement for this feature for the substances under consideration.

SPECIFIC HEAT OF LIQUID.

Ammonia, 0.886 to 1.228.

Sulphur dioxide, 0.277, 0.33, 0.41.

Carbon dioxide, 0.60, 0.79, 1.00.

Values commonly used for ammonia are close to unity.

As the losses for liquid cooling are dependent upon the value for specific heat, the values given in the accompanying table only apply for the values for specific heat given.

LOSSES IN REFRIGERATING EFFECT DUE TO LIQUID COOLING PER POUND.

Temperature, F.			Specific Heat of Liquid.			Loss of Refrigerating Effect						Net Refrigerating Effect Available, B. T. U.		
						In B. T. U.			In Per cent. of Heat of Vaporiz'n.					
Min.	Max.	Range.	NH_3	SO_2	[illegible]	NH_3	SO_2	CO_2	NH_3	SO_2	CO_2	NH_3	SO_2	CO_2
2°	85°	83°	1.00	0.40	0.80	83	33.2	66.3	15%	28.1%	56.2%	471.27	137.6	51.8
2°	73°	71°	1.00	0.40	0.80	71	28.1	56.2	12.8%	16.5%	47.5%	483.27	142.7	62.

Volume of Compressor :—Now that we have a value for the refrigeration available per pound of refrigerant we can undertake to determine the size of the compressor. To do this it is necessary to have data as to the volume of a pound of refrigerant as well as the number of pounds required. The former is determined from the tables and the latter from the refrigerating duty required.

For purposes of comparison it is of course possible to determine the cylinder capacity per unit of refrigerating effect, using values from tables as basis.

CYLINDER CAPACITY PER UNIT REFRIGERATING EFFECT.

TEMPERATURE F.		PRESSURE OF VAPORIZATION ABSOLUTE.			VOLUME OF 1 POUND OF VAPOR.			REFRIGERATING EFFECT OF 1 POUND.			VOLUME FOR REFRIGERATING EFFECT OF 1 B. T. U.						RELATIVE CYLINDER CAPACITY. BASIS OF CO_2		
		Pounds Per Square Inch.			Cubic Feet.			B. T. U.			Cubic Feet.			Cubic Inches.					
Of Vaporization.	Of Liquid.	NH_3	SO_2	CO_2	NH_3	SO_2	CO_2	NH_3	SO_2	CO_2	NH_3	SO_2	CO_2	NH_3	SO_2	CO_2	NH_3	SO_2	CO_2
2°	85°	31.84	11.1	322	8.63	7.04	.259	471.27	137.6	51.8	.01866	.0512	.005	32.2	88.3	8.64	3.73	13.54	1.00
2°	73°	31.84	11.1	322	8.63	7.04	.259	483.27	142.7	62.0	.01787	.0494	.00418	30.84	85.3	7.22	4.26	11.82	1.00

The relative cylinder capacity as obtained from the preceding table differs somewhat from the value sometimes assigned by authorities, the explanation being that the latter represent practical ratios for normal conditions, and furthermore, that the differences may be due to some extent to differences in fundamental data.

It may be of some interest to give some of these values, reduced to basis for CO_2.

RELATIVE CYLINDER CAPACITY ON BASIS OF CO_2.

Authority.		NH_3	SO_2	CO_2
Kroeschell Bros		5.77	14.20	1.00
Stetefeld		4.85	13.54	1.00
Goosmann		5.00	13.5	1.00
Lorenz	(68° to 14° F.)	4.45	12.0	1.00
	(50° to 14° F.)	5.64	13.9	1.00
From preceding table	(85° to 2° F.)	3.73	10.24	1.00
	(73° to 2° F.)	4.26	11.82	1.00

The refrigerating duty required would of course be the number of heat units abstracted in the refrigerator in a given time. Dividing this value by the value for volume for refrigerating effect of 1 B. T. U. would give the volume duty for the compressor for the given time.

We will assume the refrigerating duty to be 1 B. T. U. per minute for the temperature conditions that have been given. For convenience we will give the equivalent of this rate in other units.

EQUIVALENT OF 1 B. T. U. PER MINUTE IN OTHER UNITS.

1 B. T. U. per minute $= 1 \times 60 = 60$ B. T. U. per hour.
$= 60 \times 24 = 1440$ B. T. U. per 24 hours.
$= 1440 \div 284{,}000 = .0050704$ tons per 24 hours.
$= 1 \times 778 = 778$ foot pounds per minute.
$= 778 \times 60 = 46680$ foot pounds per hour.
$= 46680 \times 24 = 1090320$ foot pounds per 24 hours.
$= \frac{778}{33{,}000} = .02358.$ HP.

We are now ready to consider the feature of stroke volume. We will need for this the speed or number of strokes per minute. From this value and the diameter and area of cylin-

der the value for length of piston travel given below is obtained from assumed values for speed and diameter.

DATA ON PISTON TRAVEL.

VOLUME OF VAPOR TO BE PUMPED PER MINUTE.			NUMBER OF STROKES PER MINUTE FOR EACH.	VOLUME OF CYLINDER.			DIAMETER OF CYLINDER IN EACH CASE.	AREA OF PISTON IN EACH CASE.	LENGTH OF PISTON TRAVEL=LENGTH OF STROKE FOR SINGLE ACTING OR ½ LENGTH OF STROKE FOR DOUBLE ACTING.			MEAN RATE OF PISTON TRAVEL.		
Cu in.				Cu. in.			In.	Sq.in.	Inches.			Feet per minute.		
NH_3	SO_2	CO_2		NH_3	SO_2	CO_2			NH_3	SO_2	CO_2	NH_3	SO_2	CO_2
32.2	88.3	8.64	70	.46	1.26	.124	6	28.27	.01628	.0446	.00439	.095	.2602	.0256
30.84	85.3	7.22	70	.44	1.22	.103	6	28.27	.01558	.0432	.00364	.0908	.252	.02122

It is of course impracticable to use equal cylinder diameters for the three mediums as assumed in the table. Their actual values would be more nearly 2, 3 and 1 for NH_3, SO_2 and CO_2 respectively.

MEAN EFFECTIVE PRESSURE:—An important feature required for the determination of the power required is the mean effective pressure. This is determined from the values for pressure in the expansion coils and in the condenser and from the curve of compression.

To assist in obtaining this value different methods have been devised, involving the use of tables. One of these tables as applied to ammonia is given herewith.

MEAN PRESSURE OF DIAGRAM OF AMMONIA COMPRESSOR.

CONDENSER PRESSURE AND TEMPERATURE.

REFRIGERATOR PRESSURE AND TEMP.

	p	103	115	127	139	153	168	184	200	218
p	t°	65°	70°	75°	80°	85°	90°	95°	100°	105°
4	−20°	41.46	43.91	46.34	48.77	51.23	53.68	56.11	58.54	60.99
6	−15°	42.72	45.38	47.90	50.74	53.40	56.08	58.86	61.40	64.08
9	−10°	44.40	47.38	50.33	53.29	56.25	59.20	62.16	65.14	68.09
13	− 5°	45.86	49.15	52.42	55.70	58.97	62.25	65.53	68.81	72.08
16	0°	46.94	50.56	54.16	57.78	61.40	65.00	68.62	72.22	75.84
20	5°	47.74	51.73	55.70	59.68	63.67	67.66	71.62	75.61	79.61
24	10°	48.04	52.40	56.77	61.13	65 51	69.86	74.24	78.59	82.97
28	15°	47.88	52.67	57.44	62.23	67.02	71.81	76.60	81.39	86.18
33	20°	47.08	52.30	57.53	62.75	67.98	73.23	78.46	83.68	88.91
39	25°	45.06	51.34	57.05	62.75	68.46	74.17	79.88	85.58	91.29
45	30°	43.16	49.71	55.92	62.14	68.35	74.56	80.77	86.98	93.19
51	35°	40.52	47.26	54.02	60.76	67.52	74.28	81.02	87.78	94.52

For the given conditions the different pressures for ammonia would be as follows:

PRESSURE.

Minimum for $t = 2°$ F.	31.84 lbs. per square inch.
Maximum for $t = 85°$ F.	167.88 lbs. per square inch.
Mean effective pressure	72.90 lbs. per square inch.

For SO_2 and CO_2 it will answer to use for the mean effective pressure a value obtained from multiplying the value for ammonia by a factor representing the ratio of pressure for these substances.

RATIO OF PRESSURES.

	Temp. deg. F.	Pressure lbs. per sq. in. NH_3	SO_2	CO_2	Pressure ratio. NH_3	SO_2	CO_2
Minimum	2°	31.84	11.1	222	1	.348	10.1
Maximum	85°	167.88	65.3	1036	1	.390	6.17
Mean		72.90	26.84	593	1	.369	8.135

POWER REQUIRED.

From the data given the power required is readily obtained as follows:

$$HP = \frac{\text{Area of piston} \times \text{mean effective pressure} \times \text{mean rate of travel of piston}}{33{,}000}$$

POWER REQUIRED.

Temperature limits F.	Area of piston for each.	Mean affective pressure. Lbs. per sq. in. NH_3	SO_2	CO_2	Mean rate of piston travel. Feet per min. NH_3	SO_2	CO_2	Power required, horse power. Per B. T. U. per min. NH_3	SO_2	CO_2	Per ton per 24 hrs. NH_3	SO_2	CO_2
85° to 2°	28.27	72.90	26.84	593	.095	.2602	.0256	.00593	.00600	.0130	1.17	1.182	2.56
73° to 2°	28.27	72.90	26.84	593	.0908	.252	.02122	.00566	.00579	.0108	1.115	1.14	2.13

The results for the conditions given seem to show that CO_2 is considerably behind NH_3 and SO_2, as regards power required from the thermo-dynamic standpoint. Conditions could be selected that would bring them nearer together, while

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frequently in practice they would be considerably more divergent. It is evident accordingly that the choice of refrigerant is not determined entirely from a thermo-dynamic standpoint.

PRACTICAL CONSIDERATIONS :—The large dimensions of the SO_2 compressors and the use of tight-fitting leather piston packing for CO_2 compressors tend to bring the three types more nearly to equality in operative results, so that it is generally accepted that they are practically equal for normal conditions.

RESULTS OF TESTS :—Records of tests do not indicate the superiority of one of the three mediums mentioned over the other. In fact, the results of different tests on the same medium show as much variation as the results of tests for different mediums. Any set of results requires careful analysis before a true verdict can be pronounced. This is especially the case for any comparative tests, as it is not an easy matter to get together apparatus of the different types that are the best adapted to the special duty. Accordingly, while the results of tests given below are of interest and value, too much stress should not be placed on the apparent conclusions that are indicated by the same.

TRIALS AT BRITISH DAIRY SHOW.

Trials of refrigerating machinery for milk-cooling were made at the British Dairy Show in 1905, which resulted in the award being given to a machine of the SO_2 type, although an analysis of the results by Mr. A. G. Enock as reported in the British Cold Storage and Ice Association shows that the same was not warranted by the facts. We give below the revised results, as brought to a uniform basis.

COST OF POWER FOR MILK-COOLING.

Revised results of trials at British Dairy Show, 1905, on a basis of cooling 200 gallons of milk through 35.8° F.

Type of Machine.	NH_3	SO_2	CO_2
Average electric consumption in units,	9.94	12.58	11.5
Cost at 3d,	2/5¾	3/1¾	2/10½
Equivalent cost in U. S. units,	$.59½	.75½	.69½

The discussion provoked by these tests seems to indicate the impracticability of conducting a comparative test that will satisfy all parties concerned.

TESTS BY DANISH AGRICULTURAL SOCIETY.

Tests were made in 1898 by the Danish Agricultural Society on machines suitable for dairy use, the results of which are given below. The superior results of the CO_2 machine are largely explained by the fact that this machine was of considerably larger capacity, the ratio being approximately 25,000 to 15,000 Thermal Units (Danish).

The units used are Danish. The relative value of Danish units and English units is as follows: One horse power Danish is taken as representing 480 foot-pounds, as against 550 English measurement. 1 pound Danish is 10 per cent. more than 1 pound English. The thermal units are in pounds C.

COMPARATIVE TEST OF REFRIGERATING MACHINES MADE BY DANISH AGRICULTURAL SOCIETY, 1898.

System of Machine.	Temperature of Cooling Water C.		Power required per 10,000 T. U. per hour.
	Inlet.	Outlet.	H. P.
NH_3	10°	15°	1.58
CO_2	10°	15°	1.15
NH_3	10°	20°	1.92
CO_2	10°	20°	1.55
NH_3	20°	25°	2.58
CO_2	20°	25°	1.90

TESTS BY DR. LORENZ.

In the tests given below it will be noted that the refrigerating duty was smaller for the CO_2 test and that the temperature of the cooling was somewhat lower, and also that the test for NH_3 involved the use of one double-acting compressor and the front end of a second compressor.

TEST OF LINDE CO.'S NH_3 COMPRESSOR INSTALLED IN MUNICIPAL SLAUGHTER HOUSE IN MAINZ.*

Test Conducted by Prof. Dr. H. Lorenz.

HORIZONTAL DOUBLE COMPRESSOR, DOUBLE ACTING, 1 COMPRESSOR AND FRONT END OF SECOND COMPRESSOR USED = 3/2 COMPRESSOR.

Bore . . . . 270 m/m = 10⅝ in. = 10.62 in. = 88.664 sq. in. area.
Stroke . . . . 500 m/m = 19 11/16 in. = 19.6875.
Piston Rod . . . . . 60 m/m = 2⅜ in. = 2.37 in. = 4.43 sq. in. area.
Speed . . . . 76.4 Rev. per minute.
Comp. Gas Displacement . . . 5062 cb. in. per Rev. 3/2 Comp.
Comp. Gas Displacement . . . 3404 cb. in. per Rev. 1 Comp.
Comp. Gas Displacement . . . 1658 cb. in. per Rev. (front).
Comp. Gas Displacement . . . 396.861 cb. in. per minute 3/2 Comp.
Comp. Gas Displacement . . . 6920 cb. in. per ton per minute.
Water Temp. Liquid Cooler 14.8° C. = 58.6° F.
Water Temp. Inlet Cond. . . . . 15.1° C. = 59.2° F. } Submerged Condenser.
Water Temp. Overflow Cond. . . . . 23.75° C. = 74.7° F. }
Total Water Consumption . 24801 L = 5900 gal. per hour. }
Mean Condenser Temp. of NH_3 = 27.7° C. = 81.8° F.
Corresponding absolute Cond. Pr. 142 pounds.
Mean effective Pressure, 4.4 Kg/qcm. = 62.48 pounds.
Evaporating Temp. of NH_3 −10° C. = 14° F. = 28 lbs. evaporating Pr.
Comp. Work in effective H. P. meter. 63.54 H. P. = 62.65 H. P.
Actual Cooling effect, 171,380 Cal. = 678.665 B. T. U. = 57.36 Tons.
H. P. ÷ Cooling effect = 1,092 H. P. Per Ton of Refrigeration.

* "Eis & Kalteindustrie," October, 1901.

TEST OF L. A. RIEDINGER'S CO_2 COMPRESSOR INSTALLED IN THE VEREINSBRAUREI APOLDA.*

Test Conducted by Prof. Dr. H. Lorenz.

COMPRESSOR, DOUBLE ACTING, HORIZONTAL.

Bore	140 m/m = $5\frac{1}{2}$ in. = 23.75 sq. in. area.
Stroke	500 m/m = $19\frac{11}{16}$ in. = 19.69 in.
Piston Rod	70 m/m = $2\frac{3}{4}$ in. = 5.94 sq. in. area.
Speed	61.5 rev. per minute.
Compressor Gas Displacement . .	822 cb. in. per rev.
Compressor Gas Displacement . .	50553 cb. in. per minute.
Compressor Gas Displacement . .	1020 cb. in. per ton per minute.
Water Temperature Condenser . .	19.84° C. = 67.5° F.
Water Temperature Liquid Cooler	12.18° C. = 53.75° F.
Quantity of Water used, Condenser	15901 L. = 4200 gal.
Quantity of Water used, Liq. Cooler	4892 L. = 1292 gal.
Total Water Consumption	5492 gal. per hour.

Submerged Condenser.

Mean Condenser Temperature of CO_2 29.1° C. = 84.5° F.

Corresponding absolute Con. Pr. . 71.7 Kg/qcm. = 67.6 atm. gauge Pr.

Evaporating Temperature of CO_2 = —9.9° C. = 14° F.

Corresponding absolute Evap. Pr. 27.3 Kg/qcm. = 25.4 atm. gauge Pr.

Gas Volume of Cylinder per Rev. = 13.47 L. = 822 cb. in.

Effective Volume of Cylinder per Rev. = 12.60 L. = 769 cb. in. = 93% efficiency.

Comp. Work in effective H. P. . . 51.33 metr. H. P. = 50.61 H. P.

Actual cooling effect = 147,612 Cal. = 584.544 B. T. U. = 49.4 Tons.

H. P. ÷ cooling effect = 1.02 H. P. per ton of Refrigeration.

* "Eis & Kalteindustrie," November, 1901.

CHAPTER VII.

BRINE.

In the ordinary indirect method of refrigeration and in ice-making a medium is required that can be circulated in the liquid form without freezing. The most convenient medium to meet these requirements is brine. Various salts have been used for making up brine for this purpose, including magnesium chloride, sodium chloride (common salt) and calcium chloride. The properties of these different salts are to a great extent quite similar, so that in many cases there would be little to choose between them. Close inspection, however, reveals differences that need to be considered in special cases. Magnesium chloride is practically out of the race on account of the cost. It is on account of cost also that sodium chloride has practically monopolized the field for an extensive period.

The use of calcium chloride is a practical necessity where low temperatures are desired. In other cases, the virtues of calcium chloride are beginning to overcome the influence of slightly higher cost over sodium chloride, so that it may be predicted that the use of calcium chloride will become practically universal.

The explanation of the use of brine for the purpose mentioned is the fact that the freezing-point of water is reduced by the addition of a foreign substance. The amount of the reduction in boiling-point will increase with the amount of foreign substance added until the saturation point is reached. This point is reached with sodium chloride at a temperature of 60° F. with the addition of 25 per cent. by weight of salt. This condition has been taken as the 100° point of one of the scale markings on an instrument adapted to determine the density of brine, known as the salometer or salinometer.

The zero point indicates the zero condition for salt or in other words the density of pure water. The scale markings between these points mentioned indicate accordingly proportionate degrees of density.

As the density increases in the brine the specific heat is reduced, so that a larger bulk would need to be circulated to produce a certain refrigerating effect. On this account it would be desirable to keep the density as low as possible. As with low density there is a higher freezing-point it is evident that the way to avoid danger of freezing is to use high density of solution.

There is, however, a limit to which the density can be carried for the reason that the solubility decreases with the temperature. Accordingly as the temperature is reduced there is reached the point of saturation at which salt is precipitated. This may result in clogging of pipes and general disturbance of the normal conditions of the system.

Solutions in practice for sodium chloride have a density of from 40° to 90° as read on the salometer. The latter reading is rather high for sodium chloride at low temperatures but would be safe for calcium chloride, which has a freezing-point about 10° lower.

At about 70° on the salometer the freezing-points are about alike for both sodium chloride and calcium chloride, being about 9° F. At this point solutions of either would have a specific gravity of about 1.135 and the percentage salt in solution would be about 17.5 for sodium chloride and 16.5 for calcium chloride.

Below this temperature the lowest limit for freezing is reached for sodium chloride at about 0° F. while with calcium chloride it is possible to go nearly 10° lower.

The method to follow in a given case is to take readings of density and temperature and consult a table on the properties of the brine used. Regulate the solution to obtain a reasonable factor of safety against freezing on the one hand and against saturation on the other. Suitable tables for use with sodium and calcium brine are given herewith.

PROPERTIES OF BRINE.

SOLUTION OF SODIUM CHLORIDE (COMMON SALT).

PERCENTAGE OF SALT BY WEIGHT.	DEGREES ON SALOMETER AT 60° F.	DEGREES ON BAUME SCALE.	SPECIFIC GRAVITY AT 60° F.	SPECIFIC HEAT.	WEIGHT OF ONE GALLON.	POUNDS OF SALT IN ONE GALLON.	WEIGHT OF ONE CUBIC FOOT.	FREEZING POINT DEGREES F.
0	0	0	1.	1.	8.85	0.	62.4	32.
1	4	1	1.007	0.992	8.4	0.084	62.8	31.8
5	20	5	1.037	0.96	8.65	0.432	64.7	25.4
10	40	10	1.073	0.892	8.95	0.895	66.95	18.6
15	60	15	1.115	0.855	9.3	1.395	69.57	12.2
20	80	19	1.150	0.829	9.6	1.92	71.76	6.86
25	100	23	1.191	0.788	9.94	2.485	74.26	1.00

PROPERTIES OF SOLUTION OF CHLORIDE OF CALCIUM.

(CALCIUM BRINE.)

DEGREES ON SALOMETER 60° F.	DEGREES BAUME, 60° F.	SPECIFIC GRAVITY, 60 F.	PER CENT. OF CHLORIDE OF CALCIUM.	FREEZING POINT, DEGREES FAHRENHEIT.	AMMONIA GAUGE, PRESSURE LBS. PER SQ. IN.	SPECIFIC HEAT.
4	1	1.007	1	+31.10	PRESSURES 46	.996
8	2	1.015	2	+30.33	45	.988
12	3	1.024	3	+29.48	44	.980
16	4	1.032	4	+28.58	43	.972
22	5.5	1.041	5	+27.68	41.5	.964
26	6.5	1.049	6	+26.60	39.5	.960
32	8	1.058	7	+25.52	38	.936
36	9	1.067	8	+24.26	37	.925
40	10	1.076	9	+22.8	35.5	.911
44	11	1.085	10	+21.3	34	.896
48	12	1.094	11	+19.7	32.5	.890
52	13	1.103	12	+18.1	30.5	.884
58	14.5	1.112	13	+16.3	28	.876
62	15.5	1.121	14	+14.3	26	.868
68	17	1.131	15	+12.2	23.5	.860
72	18	1.140	16	+10.0	21.5	.854
76	19	1.150	17	+ 7.5	20	.849
80	20	1.159	18	+ 4.6	18	.844
84	21	1.169	19	+ 1.7	15	.839
88	22	1.179	20	— 1.4	12.5	.834
92	23	1.189	21	— 4.9	10.5	.825
96	24	1.199	22	— 8.6	8	.817
100	25	1.209	23	—11.6	6	.808
104	26	1.219	24	—17.1	4	.799
108	27	1.229	25	—21.8	1.5	.790
112	28	1.240	26	—27.0	VACUUM 1	.778
116	29	1.250	27	—32.6	5	.769
120	30	1.261	28	—39.2	8.5	.757
....	31	1.272	29	—46.3	12	....
....	32	1.283	30	—54.4	15	....
....	33	1.294	31	—52.5	10	....
....	34	1.305	32	—39.2	4	....
....	35	1.316	33	—25.2	1.5	....
....	35.5	1.327	34	— 9.7	....	....
....	36.5	1.338	35	+ 2.8	....	....
....	37.5	1.349	36	+14.3	....	....

NOTE—The + sign denotes temperature above zero; the — sign temperatures below zero.

EFFECT ON PIPING AND CONTAINING VESSELS.

The effects on piping and containing vessels of the two kinds of brine are quite diverse. Sodium brine has a corrosive effect, such as to cause a gradual deterioration of the piping and exposed metallic surfaces. While the troubles from this feature are not such as to be prohibitive, nevertheless they can be entirely eliminated by the use of calcium brine, which has no such damaging effect on the surfaces.

As calcium brine has a tendency to absorb moisture, ordinary wooden tanks cannot be used with this solution, the effect of the same being to shrink up the wood and make the tank leak. Tanks made of wood, specially treated with a hot mixture of crude paraffine and resin, have been successfully employed. The best way in any case is to discard the use of wooden tanks altogether and use tanks made of steel, especially in case calcium brine is to be used.

THE SALINOMETER OR SALOMETER.

As has been stated, the instrument used to test the density of brine is called the salinometer or salometer. This instrument is a specially-designed hydrometer, with scale markings suitable to the purpose for which it is to be used.

The scale suitable for use around the refrigerating plant has markings from zero, indicating the density of pure water, up to 100°, corresponding to a solution of 25 per cent. by weight of sodium chloride at 60° F.

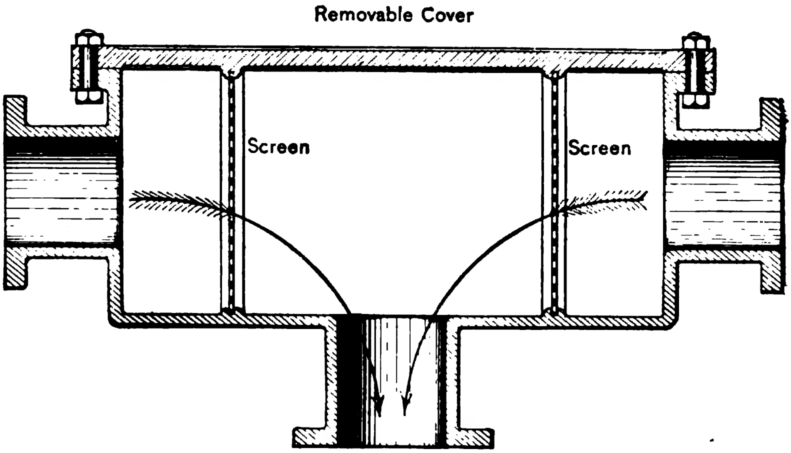
The scale used for determining the density or degree of salinity of sea water, as in a marine boiler, is based on the density at 200° F., a point taken conveniently near the boiling-point, which is 213.4° F. for sea water. The reading for sea water at normal density is one division, which represents a condition with about one-thirty-third by weight of salt.

Other standard hydrometers also extensively used are Baumé and Twaddles' densimeter. The latter is used largely in England. Baumé is more or less a standard for general use. In the United States the salinometer with 100° scale is in common use.

BRINE STRAINER.

In the preparation of brine, water as pure and clean as obtainable should be used and the vessels used for preparation and storage should be clean. Foreign matter in the brine tends to produce a slimy coating on the surface of pipes with a resulting impairment in their efficiency in heat transmission. There is always danger, even with the best of precautions, of solid particles and foreign matter being taken up and carried along with the solution. To prevent the same from damaging the pumps and clogging the valves a brine strainer

FIG. 29.



ECLIPSE BRINE STRAINER.

Box Strainer attached to Brine Suction Pump to prevent clogging of Pump Valves.

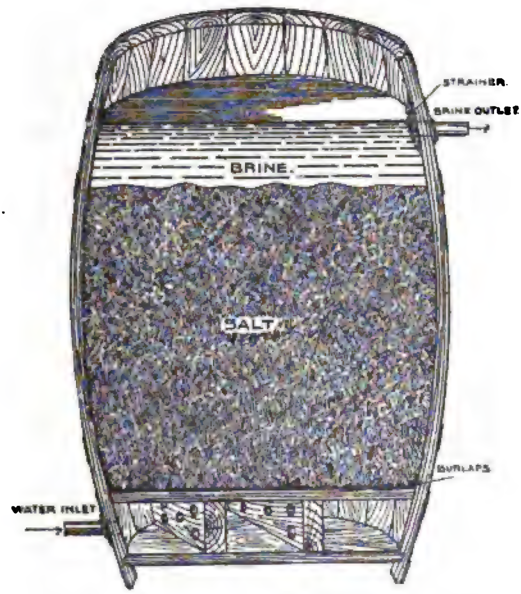
should be provided between the brine tank and the pump. A suitable device for this purpose is shown in section in Fig. 29.

PREPARATION OF BRINE.

The preparation of brine is not a particularly difficult or complicated task. Nevertheless for preparation on a large scale there is considerable labor and manipulation involved, all of which involves the use of some combination of apparatus however crude. One form of apparatus suitable for producing the solution we will refer to briefly. A sectional view of the device is shown in the illustration, Fig. 30.

The apparatus may be briefly described as a barrel that has been subjected to a species of transformation. The principle aimed at is to prepare the brine by allowing the water to percolate through a body of salt. In the arrangement to be described the water is supplied to the bottom of the body of salt and the brine is drawn off at the top. To accomplish this the barrel or cask is supplied with a false bottom about six or eight inches above the real bottom of the same. This can be made of strips of wood about an inch square in cross-section

FIG. 30.



APPARATUS FOR PREPARATION OF BRINE.

and set not more than one-half an inch apart. This false bottom is supported by two strips of wood each about six or eight inches in width, placed on edge and nailed to the bottom. These boards are perforated with holes near the bottom to permit of a free passage of water. The inlet for the water is below this false bottom.

A single thickness of burlaps is stretched across the top of the false bottom and tacked to the sides of the barrel.

The supply pipe should be of about 1¼ inch pipe, and the outlet pipe about 1½ inch pipe. The outlet pipe for the brine, which is near the top of the barrel or cask, should be supplied with a strainer to prevent chips and other bodies that should be excluded from being carried along with the brine. The supply should be from a convenient faucet or hose connection.

With the apparatus arranged as described and ready for use, the manipulation of the same is next to be considered. The first operation consists in filling the barrel above the false bottom with salt. Turn on the water next. The water, entering at the bottom and percolating through the salt, will flow out decidedly briny at the top. Furthermore, the barrel will not remain filled with salt long. As the salt dissolves more should be shoveled in. The barrel should be maintained quite full of salt by replenishing the supply as it passes away. The waste matter that rises to the top should be skimmed off. No stirring is necessary. If one barrel does not meet the demand, set up more.

Brine with either sodium chloride or calcium chloride may be prepared in the manner outlined.

CHAPTER VIII.

AMMONIA CONDENSERS.

THE function of the ammonia condenser is to condense ammonia vapor under high pressure by means of a cooling medium.

The cooling medium for the condenser is of course water. The cooler the water the less will be required. Whether fresh water or salt water is used is immaterial so long as it is economically obtained. In general, water from the city supply would be quite expensive. The most economical method for a large plant would be to pump directly from a river or lake or tide water. To do this it is not necessary for the location to be at the water front, as the expense of a pipe line would soon pay for itself, as has been demonstrated for considerable distances.

A desirable feature of any refrigerating or ice-making plant is an abundance of water at low temperature, low cost, of good quality, and especially free from such impurities as tend to form scale or a heat-resisting coating on the exposed walls that separate the water from the ammonia to be cooled.

When water is comparatively scarce the actual quantity used may be reduced to a minimum by the installation of a cooling tower.

There are a number of different types of condensers in common use, and also various modifications of those of the same type, all of which differ considerably in the results obtained as regards efficiency, economy in the use of cooling water and in operative results with different qualities of cooling water.

These various types may be classified into four different classes, respectively as submerged condensers, atmospheric condensers, shell condensers, and double-pipe condensers.

SUBMERGED CONDENSERS.

Historically the first to appear, and to a large extent to disappear, at least so far as the larger installations are concerned, was the submerged condenser.

The arrangement followed in this type is to conduct the ammonia in through coils of pipe that are submerged in a tank provided with a flow of cooling water. A suitable arrangement for this purpose is shown in Fig. 6, being similar to that used for a brine tank.

Advantage is taken in this type of the counter-current principle by having the inlet for the hot ammonia vapor at the top of the coil and outlet at the bottom, and having the inlet for the cooling water at the bottom of the tank and the overflow outlet at the top. In this way the hot vapor is brought in contact virtually with the warm water at the top and the condensed liquid is in contact with the cold water at the bottom.

The submerged condenser is not very efficient, being uneconomical in the use of cooling water, as it is not feasible to bring the greater part of the cooling water into intimate contact with the pipe surface of the coils with the ammonia. Furthermore, the transfer of heat may be reduced by a film of warm water or air bubbles adhering to the pipe or by a coating of slime and foreign matter on the pipe surface. The coils are inaccessible for cleaning and it is difficult to detect leaks, as the escaping ammonia is absorbed by the surrounding water. The tanks are heavy and bulky.

In brief, the submerged condenser answered very well in its day and might well be continued in use if there were no better to be had. They answer very well where there is an abundance of water at low cost or where water must be profusely used on account of poor quality and where space and weight are secondary considerations.

THE ATMOSPHERIC CONDENSER.

The condenser that has probably been used more extensively than any other in recent years is known as the atmospheric condenser.

This type is made up of a number of vertical stands or sections of horizontal running pipe connected at the ends by return bends, with a gutter along the top from which cooling water is admitted in fine streams along the top of the uppermost pipe, the water trickling downwards from this pipe by gravity and passing in succession over the other layers of pipe below.

The water is collected below in a pan with walls extending far enough outward to catch water that may be spattered outward from the coils. The water may be run off from the collecting pan to the sewer, or may be used for preliminary cooling or for some other useful purpose, with or without filtration, as the occasion may require.

In this arrangement the pipes and the water are exposed to the atmosphere. Accordingly, the ordinary cooling effect due to contact of the water with the surface of the pipes is augmented by the effect due to evaporation of a portion of the cooling water.

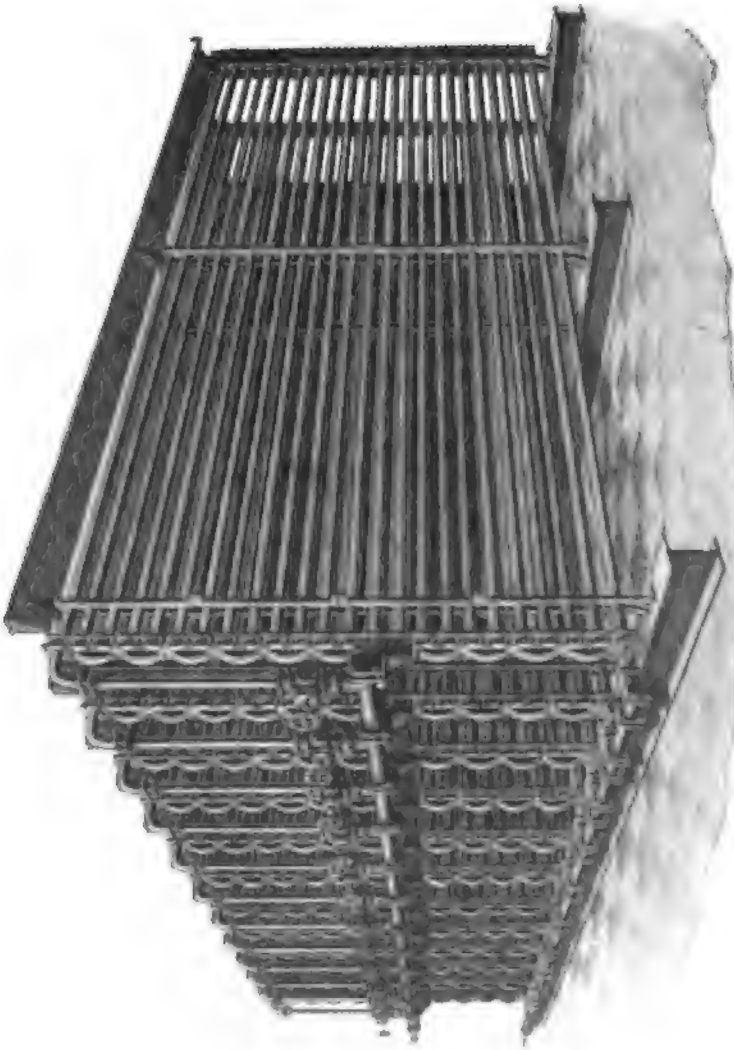
Although this type of condenser is far superior to the submerged condenser, especially in economy of cooling water, it is not an ideal apparatus for the reason that it is not possible to take full advantage of the counter-current principle.

The reason for this is that the water must be admitted along the top, so as to be allowed to flow by gravity over the rest of the coil below. On this account, to obtain the best effect from the cooling water it would be necessary to have the hot vapor from the compressor delivered to the lowermost pipe of the condenser stand and draw the condensed liquid off from the top. It is obvious that this cannot be done, as the liquid as formed would flow downward and gather in the lower pipes of the stand.

The condenser shown in Fig. 31 is provided with galvanized water troughs with leveling device and also with perforated drip strips between the layers of pipe to facilitate the distribution of the water over the length of the pipe and to facilitate the air cooling.

Each section of the condenser is supplied with a stop-valve

FIG. 31.

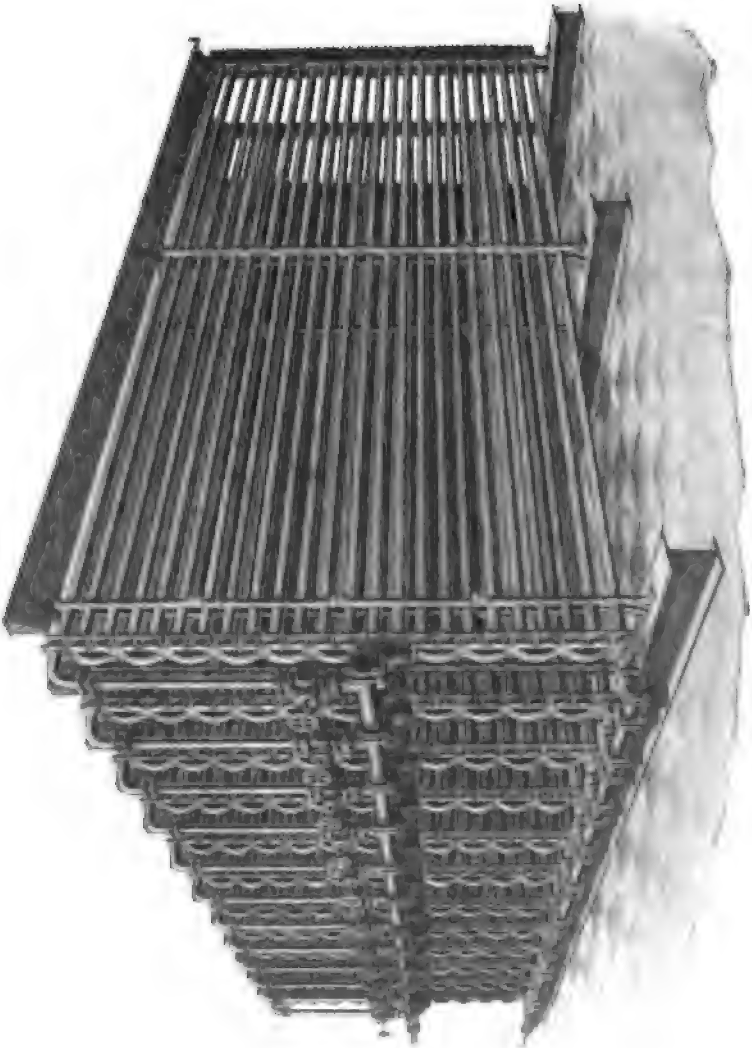


WOLF ATMOSPHERIC AMMONIA CONDENSER.

FIG. 32.

COUNTER-CURRENT ATMOSPHERIC AMMONIA CONDENSER.

Fig. 31.

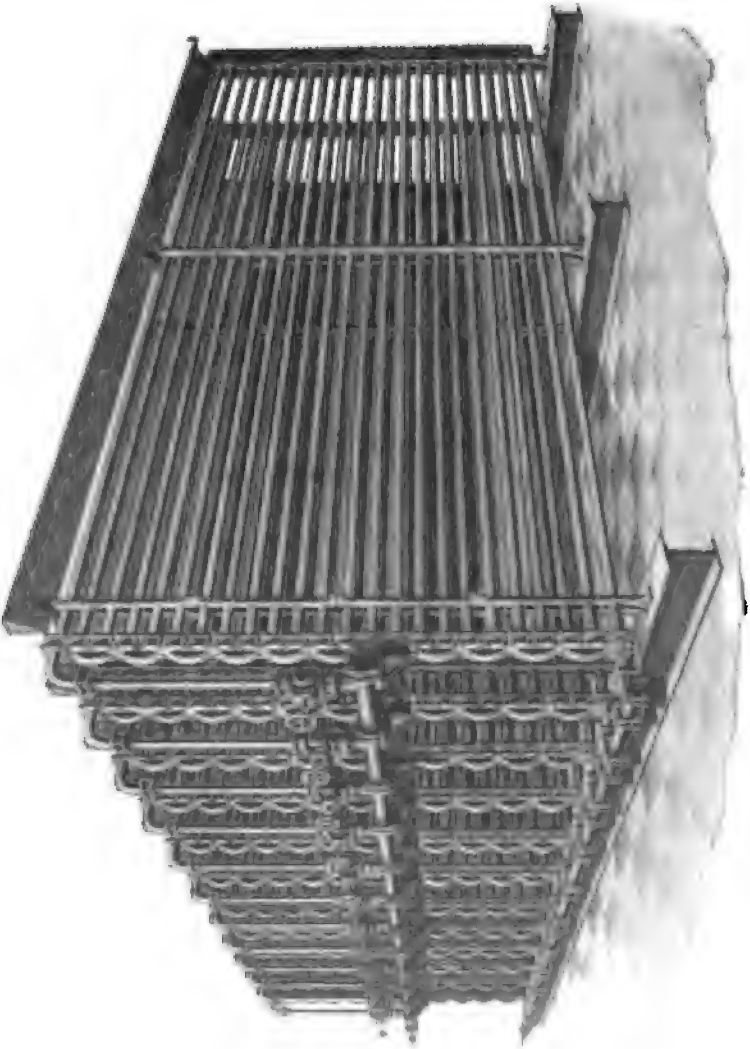


WOLF ATMOSPHERIC AMMONIA CONDENSER.

FIG. 32.

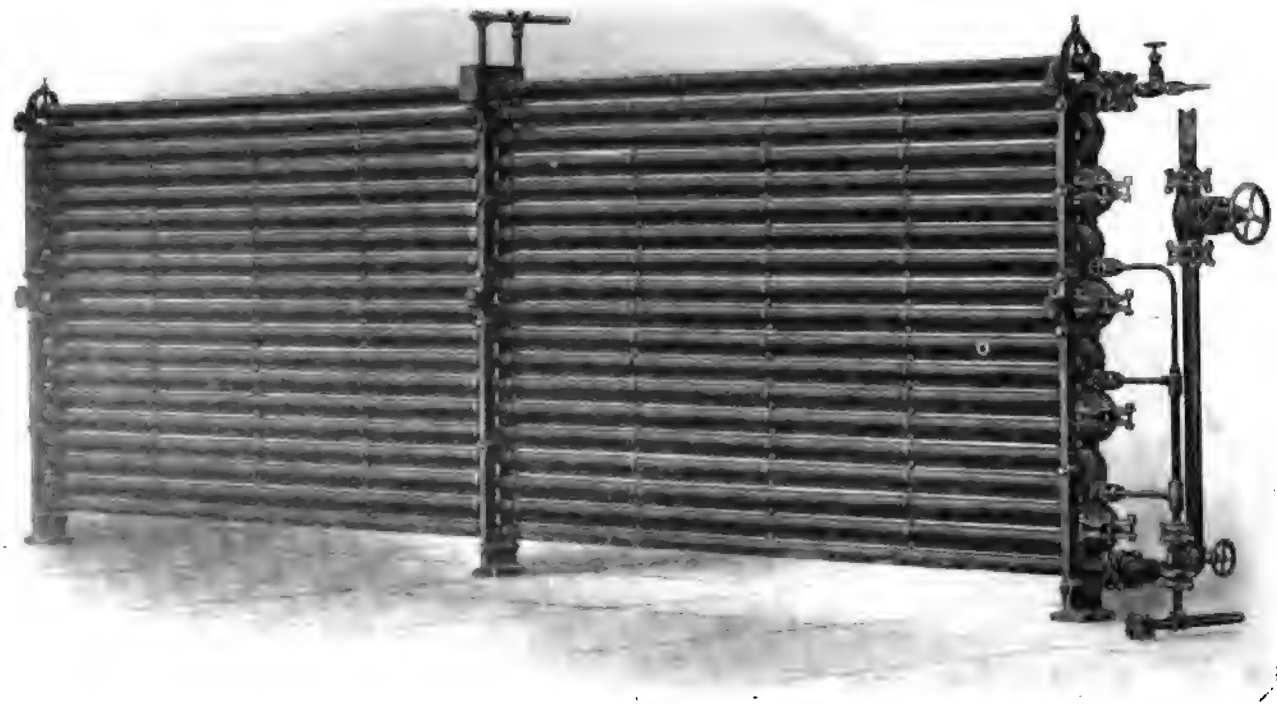
COUNTER-CURRENT ATMOSPHERIC AMMONIA CONDENSER.

Fig. 31.



WOLF ATMOSPHERIC AMMONIA CONDENSER.

FIG. 32.

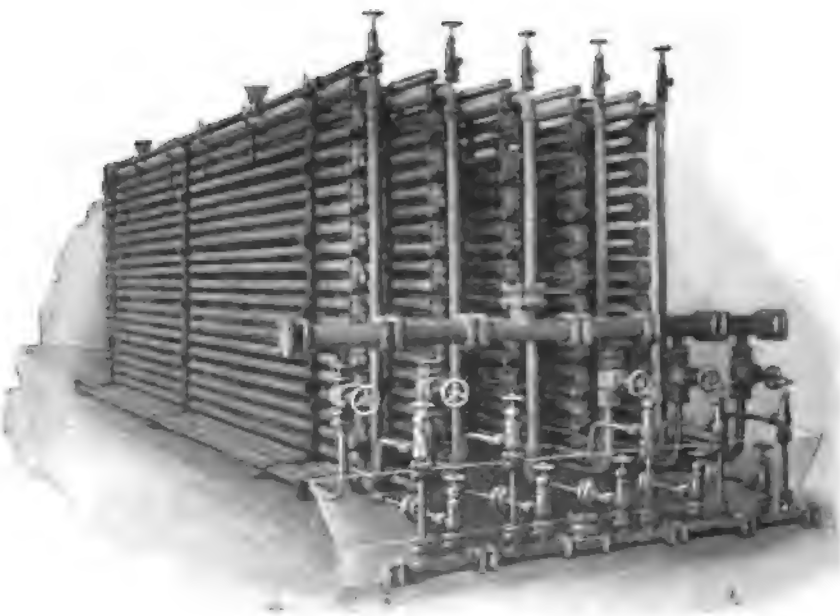


COUNTER-CURRENT ATMOSPHERIC AMMONIA CONDENSER.

on the inlet and outlet, so that any section can be shut off without interfering with the operation of the others. The condenser is also provided with an auxiliary header having a stop-valve at each section, so that when connected to the suction of the compressor, any section can be evacuated of ammonia without interfering with the operation of the remaining sections.

A close approach to the counter-current principle is reached in the plan followed in the condenser shown in Fig. 32. In

FIG. 33.

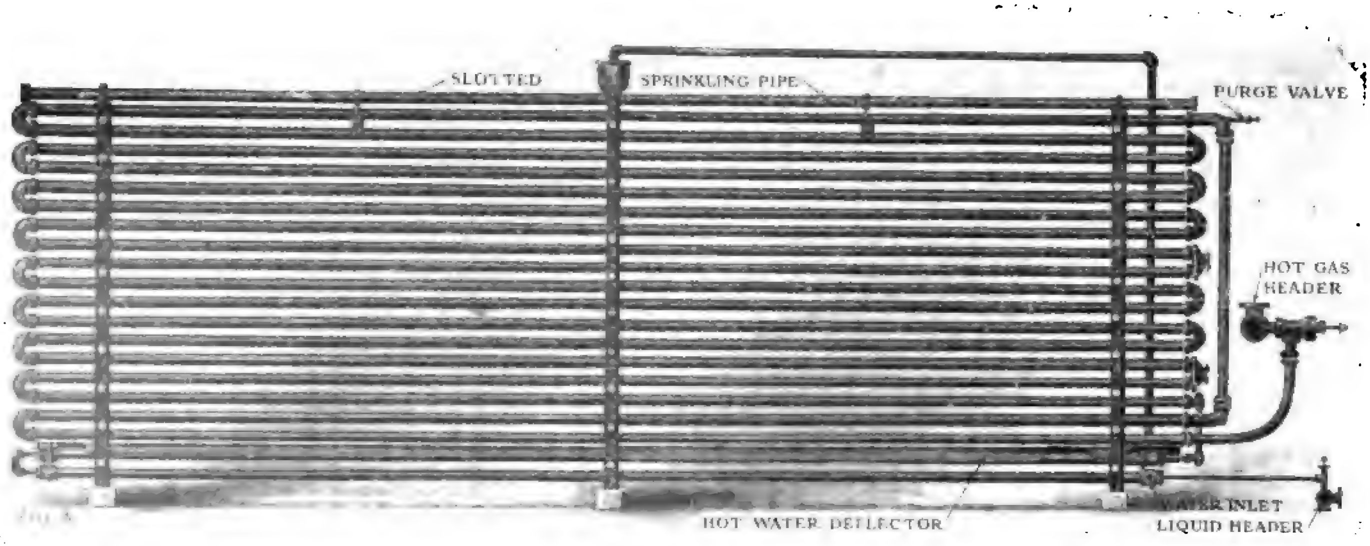


YORK ATMOSPHERIC CONDENSER WITH FORE-COOLER.

this the hot vapor is admitted at the bottom and the condensed liquid is drawn off practically as formed by means of small liquid pipes tapped into the pipes of the condenser stand at different levels, the liquid being collected in a liquid header or storage tank at the base of the condenser.

A sort of compromise between top and bottom feed is shown in Fig. 33, in which hot vapor is first admitted to a prelimi-

FIG. 34.



ECLIPSE AMMONIA CONDENSER AND LIQUID COOLER.

nary section of four pipes in a horizontal plane submerged in the water collected at the bottom in the drip pan, from which the vapor is delivered to the top of the vertical section, which consists of 20 pipes, the liquid outlet being at the bottom.

The object of the preliminary section is to remove the heat of compression and excess heat before the vapor is brought in contact with the cold condenser water at the top.

The preliminary section is provided with a drain and trap leading to the liquid header to trap off any liquid that may be formed and to prevent the section from becoming gas bound.

The condenser shown in Fig 34 includes the feature of gas fore-cooling in the two lower lengths of pipe of the condenser proper and liquid fore-cooling in a double pipe arrangement at the bottom. By this arrangement the liquid may be delivered to the expansion valves within three degrees of the temperature of the cooling water instead of 15 degrees, as with the ordinary condenser.

SHELL TYPE CONDENSER.

A type of condenser that meets with considerable favor is known as the shell type, shown in Fig. 35. Structurally it consists of a vertical cylindrical shell with coils of pipe arranged internally, with ends for connections passing through the top and bottom heads.

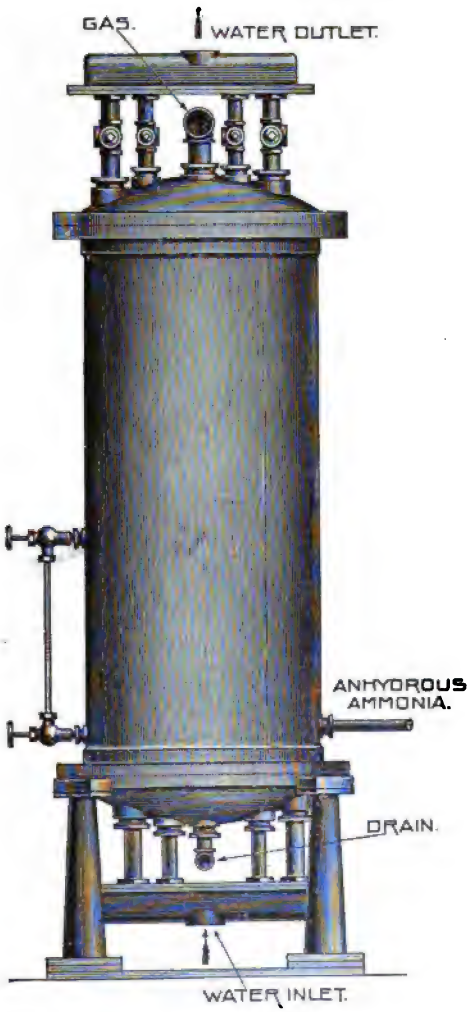
The coils are used for the circulation of cooling-water, with admission at the bottom and outlet at the top, the ammonia vapor being admitted to the surrounding space from the top, the condensed liquid collecting in the bottom. By this arrangement full advantage is taken of the counter-current principle.

Furthermore, by using the bottom of the condenser for liquid storage the liquid receiver may be dispensed with, the features of the condenser and receiver being combined.

This condenser may be briefly described as a sort of reversed submerged condenser, such as shown in Fig. 6, which shows a construction applicable for a condenser or brine tank. There

is, however, a vital difference in the arrangement of the cover and the details of construction of the shell, which in the shell-

Fig. 35.



THE POLAR CONDENSER.
Isbell-Porter Company.

type condenser must be adapted to retain vapor under high tension. Also, there is no insulation provided on the outside.

It will be noted from the plan of construction that comparatively few high-pressure joints are required for ammonia and that these when once made tight are not liable to disturbances due to changes in temperature. The direct ammonia connections are made rigid, and the changes in the coil length are readily taken up by the coils within the shell without effecting the packed joints around the water pipes in the heads.

They can be used in almost any location and with any kind of water that can be made to flow through the cooling pipes. The internal arrangement is not such as to produce a rapid interchange of heat between the ammonia and the cooling water. By providing ample surface however the results may be as good as the best. A good point in their favor is the fact that the resistance to the flow of ammonia vapor is down to the minimum.

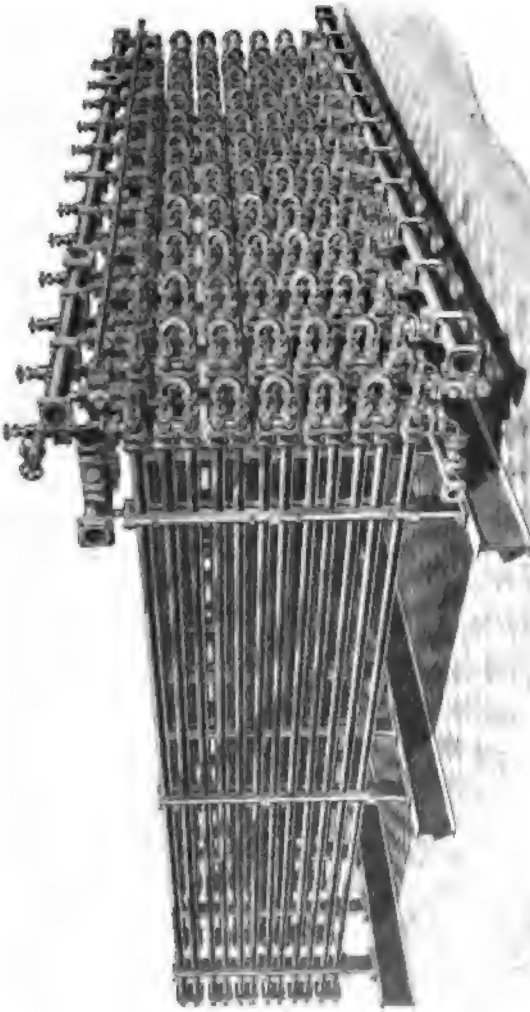
THE DOUBLE-PIPE CONDENSER.

Within a few years that almost ideal condenser has appeared, known as the double-pipe condenser. This type of condenser is generally made up in vertical stands of double pipe, the cooling-water being circulated in the inner pipe and the ammonia in the annular space between the outer surface of the inner pipe and the inner surface of the concentric outer pipe. By this arrangement it is possible to obtain about as intimate a relation between the vapor to be condensed and the cooling medium as could be desired and also to take full advantage of the counter-current principle. The ammonia vapor is admitted at the top, the condensed liquid collecting in the bottom pipes, while the cooling-water is admitted at the bottom and discharged at the top.

While a poor double-pipe condenser will probably excel the best of any of the other types for normal conditions, considerable thought and ingenuity have been expended in an endeavor to improve the details so as to obtain the best results.

The problems involved concern details of construction and of operation. There is no question that the construction is quite complicated, calling for special fittings and a large num-

Fig. 36.



WOLF DOUBLE-PIPE AMMONIA CONDENSER.

ber of joints. These structural features, however, have been successfully met in practice, so that this cannot be regarded as prohibitive.

In regard to details of operation, an important feature is that of relative space for passage of ammonia and cooling-water. The pipes used are commonly 1¼″ for the inner, for the cooling-water, and 2″ for the outer, for the ammonia. As the cooling-water undergoes no change in dimensions, practically at least, a pipe of uniform dimensions is proper. In the case of the ammonia, however, which is received as a vapor or gas and delivered as a liquid, there is involved an enormous change in volume. Consequently it would be desirable to make the relative passage for the vapor as received considerably larger than for the liquid that is discharged.

While the small space for the ammonia is desirable from the standpoint of efficient heat transfer to the cooling-water, where the specific volume of the gas or vapor is high there may result excessive friction. A number of schemes are in use to avoid this effect.

In the condenser shown in Fig. 36 the outer pipes in the upper layers are larger than those below, thus affording more space relatively for the hot ammonia vapor than for the cooler vapor and liquid below. In this case the two upper outside are of 2½-inch pipe and those below of 2-inch pipe. For the water pipe 1¼-inch pipe is used throughout.

In Fig. 37 is shown an arrangement which ought to result in a reduction of the friction to about one-fourth that for the ordinary arrangement. It will be noted that ammonia is admitted to the middle of the length of piping, the flow being divided to right and left and again uniting at the center.

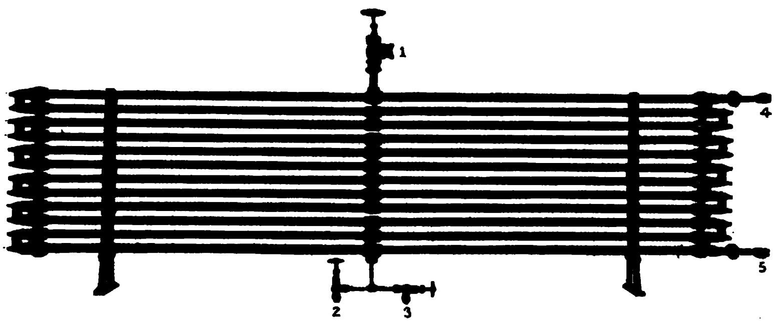
These condensers are known as the "W." and "C." type. They are made of 1¼-inch and 2-inch pipe.

Data in regard to these condensers are given below, the capacities being based on 70 degrees for cooling-water.

DATA ON "W" AND "C" DOUBLE-PIPE CONDENSER.

CAPACITY FOR REFRIGERATION TONS.	NUMBER OF PIPES IN HEIGHT.	LENGTH OVER ALL.	SHIPPING WEIGHT.
2	2	17-6	400
4	4	17-6	750
6	6	17-6	1100
8	8	17-6	1375
10	10	17-6	1650
12½	12	17-6	1900
15	14	17-6	2150

FIG. 37.



YORK DOUBLE-PIPE AMMONIA CONDENSER "W." AND "C." TYPE.

1. Gas inlet. 2. Liquid outlet. 3. Pumping out connection. 4. Water outlet. 5. Water inlet.

A good arrangement to follow is to remove the excess heat in a fore-cooler. The only danger in this is in possible condensation in the fore-cooler, resulting in holding back of gas and general disturbance until removed.

Any of the various different styles of double-pipe condensers is capable of giving good satisfaction, provided the water is reasonably free from impurities tending to produce restriction of the passageways and clogging of the pipes.

One of the strong points in this type of condenser is the fact that as the water is under pressure throughout the apparatus it is possible to make further use of the same for any purpose desired.

Furthermore, being self-contained, clean, and dry on the outside, the double-pipe condenser can be located in any convenient place without causing trouble or nuisance.

In regard to both economy in the use of water and in the minimum amount of cooling surface required the double-pipe condenser outranks all others.

The shell type condenser may be brought to the same condition as to water requirement by the use of about double the cooling surface.

The atmospheric condenser requires a greater quantity of cooling-water than the double-pipe condenser and about three times the amount of cooling surface.

The submerged condenser requires considerably more cooling-water than any of the others, but may be made up with from three-fourths to one-half the cooling surface of the atmospheric type or 50 per cent. more than for the double-pipe condenser.

The actual amount of cooling surface used for the submerged type ranges from 20 to 35 square feet per ton of refrigeration.

For atmospheric condensers from 30 to 40 square feet per ton are used.

The amount of water used for the atmospheric condenser varies from ¾ to 1¾ gallons per minute per ton of refrigeration, an allowance of 1 gallon per minute being a fair average, based on an approximate rise of 10° F. for the temperature of the water.

A rough table for relative values for cooling surface and water consumption for the different types of condensers is given below.

RELATIVE VALUES FOR COOLING SURFACE AND WATER CONSUMPTION.

Type of Condenser.	Cooling Surface.	Water Consumption.
Submerged	1	1
Atmospheric	1.33–2	.5–.8
Shell	1.33	.5
Double-pipe	.66	.5

CHAPTER IX.

RELATIVE CAPACITY FOR REFRIGERATING AND ICE-MAKING.

THE rating of refrigerating machines is based on equivalent ice-melting capacity. A refrigerating duty of one ton a day would be considered as equivalent to that produced by the melting of a ton of ice in 24 hours. The equivalent of this value in heat units would simply represent the latent heat of fusion or melting, which would be the same in amount as the latent heat of freezing. As the latent heat of freezing for one pound of water is equivalent to about 142 B. T. U., the total latent heat of melting or freezing for one ton is equal to

$$2000 \times 142 = 284{,}000 \text{ B. T. U.}$$

This value applies strictly to the condition of normal atmospheric pressure of 14.7 pounds per square inch, corresponding to a height of the mercury column in the barometer of 30 inches, and a temperature of 32° F. or 0° C.

The heat unit known as the British Thermal Unit or B. T. U. is the amount of heat required to raise one pound of water one degree Fahrenheit. This is equivalent in units of work to 778 foot-pounds.

The 284,000 B. T. U. mentioned above as the equivalent of one ton of refrigeration represents the number of heat units received by the refrigerant at the lower temperature limit in the refrigerator and discharged to the condenser cooling-water at the higher temperature limit. The heat discharged at the higher temperature would also include an additional amount representing the energy required to produce the transfer of heat mentioned from the lower to the higher temperature.

The relation of the heat received and the heat discharged would be proportional to the absolute values of the temperatures.

Let Q_2 = heat received at absolute temperature T_2

Q_1 = heat discharged at absolute temperature T_1

$Q_1 - Q_2$ = heat equivalent of work required.

Then $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$

$$Q_1 = Q_2 \times \frac{T_1}{T_2}$$

$$Q_1 - Q_2 = Q_2 \left(\frac{T_1 - T_2}{T_2}\right)$$

The relation of heat transferred to the energy required to perform the transfer, known as the coefficient of performance, is expressed as follows:

$$\frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

The equations represent, of course, the theoretical basis for a given set of conditions and do not allow for losses and irregularities that are inevitable in the attempt at practical application of any process.

We may assume temperature limits for the purpose of working out an example. We will assume two sets of values as follows:

1st. 2° F. to 85° F.: $T_2 = 462.7°$ F.
$T_1 = 545.7°$ F.
$\frac{T_1}{T_2} = 1.18$

2d. 2° F. to 73° F.: $T_2 = 462.7°$ F.
$T_1 = 533.7°$ F.
$\frac{T_1}{T_2} = 1.152$

Accordingly:

$$Q_2 = 284{,}000 \text{ B. T. U.}$$

$$Q_1 = Q_2 \times \frac{T_1}{T_2}$$

$$= 284{,}000 \times \frac{545.7}{462.7}$$

$$- 335{,}000 \qquad \text{(1st)}$$

$$= 284{,}000 \times \frac{533.7}{462.7}$$

$$= 327{,}000 \qquad \text{(2d)}$$

The work in each case is found from the difference between the two heat values, thus:

$$Q_1 - Q_2 = 51{,}000 \text{ B. T. U. per 24 hours}$$

$$= \frac{51{,}000 \times 778}{24 \times 60} = 32{,}554 \text{ ft. lbs. per minute}$$

$$= \frac{32{,}554}{33{,}000} = .987 \text{ horse power} \qquad \text{(1st)}$$

$$= 43{,}000 \text{ B. T. U. per 24 hours}$$

$$= 23{,}232 \text{ ft. lbs. per minute}$$

$$= .704 \text{ horse power} \qquad \text{(2d)}$$

It will be noted from the formula

$$Q_1 - Q_2 = Q_2 \frac{(T_1 - T_2)}{T_2}$$

1st. That the actual amount of work required in a given case depends upon the range of temperatures, and

2d. That the value for heat units received at the lower temperature, or in other words the refrigerating duty, is a measure of the work to be performed.

As definite temperature limits have not been agreed upon for determining the unit of refrigeration, no definite and absolute value can be assigned for this unit.

Since, however, the refrigerating duty is a measure of the work to be performed, we may in a given case compare the duty represented by the ice-melting only and that required for the actual production of the equivalent amount of ice on the basis mentioned.

The duty of a 1-ton machine would be represented by 284,000 B. T. U. per 24 hours. The duty involved in the production of one ton of ice would include the 284,000 B. T. U. representing the latent heat of freezing and also two other items, respectively the heat units required to bring the water

down to freezing temperature and the heat units required to cool the ice down from freezing temperature to the lowest point reached, or in other words, to the so-called temperature of freezing.

The amount of heat involved in each of these cases depends upon the range of temperature and the specific heat. The values for the latter are 1.00 for water and about 0.5 for ice.

In case the initial temperature of the water is 80° F. and the final temperature of the ice 20° below freezing or 12° F. the range of temperature would be $80° - 32° = 48°$ for the water and $32° - 12° = 20°$ for the ice.

On this basis there would be added duty of 48 heat units per pound for cooling the water and $0.5 \times 20 = 10$ heat units per pound for cooling the ice. Thus to produce the one pound of ice we have to remove, in addition to the 142 units for the simple freezing, $48 + 10 = 58$ units, making a total of $58 + 142 = 200$ heat units. For 1 ton the total amount would be $200 \times 2000 = 400{,}000$ heat units.

Under the conditions named a two-hundred-ton refrigerating machine would be capable of producing only 142 tons of ice. This difference is increased rather than decreased by the incidental and unavoidable losses from the tanks, handling, and storage.

Accordingly, the rating of machines for ice-producing is much lower than for refrigerating, being commonly given at from 50 to 60 per cent., so that a hundred-ton refrigerating machine would be rated as a 50-ton or 60-ton ice machine. It is evident that this rating is merely nominal, and that the ratio would depend upon the existing local conditions in a given case.

CHAPTER X.

INSULATION.

THERE is nothing more self-evident in connection with the subject of refrigeration than the necessity of good insulation. All agree that insulation is a good thing, and is something that we cannot have too much of, so far as concerns the economy of operation of the plant. But economy of operation is one thing, and economy of insulation is another. Fortunately, however, good insulation is by no means so expensive as to be prohibitive. The principal thing, of course, is to know what is to be accepted as satisfactory. Perfection cannot be attained. When it is considered that the losses due to imperfect insulation are continuous during the operation of the plant, it is plain that any gain in checking this waste is to be measured in its effect on the coal-pile.

The subject of insulation may be conveniently considered from two aspects : first, as applied to pipes, or pipe insulation ; second, as applied to buildings, or building insulation.

In neither case is it possible to set down many rules that are generally followed. Ideas as to details on the subject are about as numerous as the individuals concerned.

A list of the materials used includes brick, wood, asphalt, concrete, pitch, mineral wool, felt paper, cork, charcoal, and by no means the least important, air.

Loose packing should be avoided, as being liable to settle and leave clear space.

PIPE INSULATION.

For exposed piping there are numerous kinds of insulation on the market. Wool, felt, and cork are the principal non-conductors used. The insulation is produced in suitable lengths, either split lengthwise to admit the pipe or made up in half sections. Canvas may be used outside.

For underground pipe good success has been obtained by laying the pipes in boxes made of creosoted plank, and filling the space between the pipes and box with a mixture of pitch and cork.

Experience seems to demonstrate that this system of pipe insulation is capable of producing highly satisfactory results. Rooms at hundreds of feet distance are maintained at below-zero temperature. The change in temperature of brine in being transmitted this distance is scarcely appreciable.

In one case brine is conducted by an eight-inch pipe a distance of 1500 feet to a distributing point, the rise in temperature being but two degrees above the temperature of the pump. For a considerable portion of the distance, the brine pipe passes through a tunnel parallel to a steam pipe about five feet distant. Although the brine is about zero in temperature and the steam 344 degrees F., the temperature of the brine is practically not affected by the heat of the steam.

BUILDING INSULATION.

The value of air spacing is generally admitted for the insulation of buildings or rooms. Some advocate the use of mineral wool, while others use none, practically confining themselves to air spacing properly constructed.

Air is a good insulator if so confined as to avoid the formation of appreciable convection currents. Surfaces should accordingly be made air-tight. To accomplish this, pitch is used with masonry and paper with wood. Good sheathing, double, with paper between, may be considered as a requisite in some part of the structure.

As a matter of fact it is considered practically impossible to construct air spaces with the desired tightness of joints to ensure proper confining of the air within the spaces and avoid circulation of the air so as to destroy the effectiveness of the insulation. Accordingly, the present practice seems to run towards avoidance of open air spaces and using some filling material for otherwise open spaces.

Substances employed should, of course, emit no unpleasant odor, and should not tend to absorb moisture.

For freezing-chambers the insulation should be improved in comparison with the insulation for a refrigerating chamber, in accordance with the difference in temperature, as the flow of heat depends upon this difference.

More extended reference to this feature will be found in the section on *Structural Insulation.*

LOSSES OF REFRIGERATION.

The losses of refrigerating effect may be studied from the consideration of the losses of heat in the case of warm bodies.

Losses of heat occur through three methods of heat-transfer, by radiation, by conduction, and by convection. The losses of heat through all three of these processes is more or less involved in the method of insulation employed.

In the case of a cold body, as of a cold-storage chamber which receives heat from outside, the methods for the entrance of heat are by absorption, conduction and convection.

The term radiation is applied to the process of emission of heat from the surface of a warm body to a colder body through intervening space, the term absorption applying to the reception of heat by the colder body.

RADIATION.

The loss of heat by radiation depends upon the radiating power of the substance, and the difference in temperature between the surface radiating and the surface receiving the heat. Consequently the amount of heat radiated from the outside wall of a chamber would depend upon the difference between the temperature of the wall and the surrounding bodies. Good insulation may reduce the losses due to this process by serving to maintain a greater difference in temperature between the inner and the outer or exposed surface of the wall, and consequently a smaller difference between the temperature of the outer surface of the wall and the surrounding space.

There is little choice in regard to radiating power of material for the materials available for constructing refrigerating structures. The values for the radiating power for such ma-

terials are about alike, being equivalent to a loss or gain of about .75 heat units per square foot of surface per hour for one degree difference in temperature.

CONDUCTION OF HEAT.

The rate of conduction of heat through a wall depends upon the conducting power of the material, upon the difference in temperature between the two exposed surfaces, upon the thickness of the wall, and upon the area of the surface.

The relation of these features is shown by the formula

$$H = \frac{C \times A \times (T - T_1)}{d}$$

in which

H = Heat conducted in heat units.
A = Area of surface in square feet.
T = Temperature of surface on one side.
T_1 = Temperature of surface on other side.
d = Thickness of wall.
C = Constant representing the conducting power of the material of wall.

The values for the constant "C" for various substances are given in the table shown herewith, these values representing the heat units per hour conducted through one square foot of surface one inch in thickness per degree difference in temperature.

COMPARATIVE VALUE OF INSULATING MATERIALS.

Kind of Material.	*Conducting Power C.*	*Kind of Material.*	*Conducting Power C.*
Copper	515.	Brick dust	1.33
Iron	233.	Coke dust	1.29
Zinc	225.	Cork	1.15
Marble	28.	Chalk powder	0.87
Stone	17.	Charcoal powder	0.64
Glass	7.	Straw chopped	0.56
Brick work	5.	Coal dust	0.54
Plaster	4.	Hemp canvas	0.41
Double windows	3.6	Muslin	0.40
Oak wood	1.7	Writing paper	0.34
Walnut wood	0.8	Cotton	0.32
Pine wood	0.75	Air confined	0.3
Saw dust	0.55	Gray blotting paper	0.27
India rubber	1.37		

The name Peclet is intimately associated with the subject of the laws and data in regard to the transfer of heat.

CONVECTION.

The loss of heat by convection currents of the air depends upon the difference in temperature of the surface and the air in contact with the same and upon the nature of the surface. By nature of the surface is meant the form or contour of the surface. The nature of the material forming the surface has no bearing on the result. The loss by convection is greatest with a flat vertical surface. For such a surface the loss per unit of area diminishes somewhat with an increase of height. The formula for such a surface as given by Box is as follows:

$$l = .361 + \frac{.233}{\sqrt{h}}$$

in which

l = loss in B. T. U. per hour per square foot per degree difference in temperature.

h = height in feet.

Values obtained from this formula for different heights of surface are given in tabular form below.

HEAT LOSS BY CONVECTION.

Height in feet. h.	Loss in B. T. U. l.
10	.4347
25	.4076
64	.3901
100	.3843

In confined air spaces the facility for formation of convection currents and the heat losses attendant upon the same increase with an increase of the width of the space so that there is practically no net gain in insulation value by increasing the width of such surfaces, the gain through an increase in thickness of the wall of air being off-set by the increased losses through convection currents.

Accordingly, if air spaces are provided, only thin strata of

air should be used. The office of packing material is to break up the air spacing into small cells, the air itself being the most effective feature of the combination.

PRACTICAL CONSIDERATIONS.

From a practical standpoint the wall of a refrigerated chamber is a composite structure with an insulating value that can be expressed in figures representing the loss in heat in B. T. U. per square foot of surface per degree difference in temperature for the air space on each side.

Values as low as .75 B. T. U. per square foot per degree can be obtained. For freezing-chambers the value should be at least below 1.00. The construction actually followed in many cases, however, would not give results as good as this.

Where comparatively high temperatures are maintained a construction giving double the values would be admissible.

In calculating the losses, the effect of windows and doors must be taken into consideration. As this feature is somewhat uncertain, an approximate value that may be used to include all features would be from 4.00 to 5.00 B. T. U. per square foot per degree difference in temperature. From this value and the area of the enclosing walls of the refrigerated space the amount of refrigeration to be supplied to make up for losses through the walls can be obtained.

As these losses represent more than one-half the work of the plant, a safe value for the entire refrigerating duty of the plant can be obtained by doubling the value for the losses obtained as above.

CHAPTER XI.

REFRIGERATION REQUIREMENTS FOR AIR COOLING.

OUTSIDE of the special industry of ice-making nearly all results of refrigeration are brought about by means of air cooling.

This statement applies in the cold storage ware-house to the cooling or freezing effected in a tightly-closed room, or a room or series of rooms or chambers provided with air circulation, whether moderate for the purpose of freshening the air or at a rapid pace for the purpose of facilitating refrigeration, as in the indirect air system. In these cases the cooled air serves as a means to an end.

In the case of air cooling for auditoriums or public buildings, or for mines or for special industries, such as chocolate factories, the cooled air is the primary product desired.

Then there are the cases where the object of the refrigerating process is the drying of the air by freezing out the moisture, as is done with air supplied to blast furnaces.

This last idea suggests the fact that in any case we do not have simple plain air to deal with, but rather a mixture of air and moisture. Incidentally, where there are persons working and lamps burning, each of these adds to the features of heat and moisture to be removed.

COOLING DRY AIR.

In this item we are to consider only the feature of cooling pure air. In this case the heat removed would depend upon the range of temperature and the specific heat for constant pressure for air. As air is commonly measured by volume it is convenient to have the value for specific heat expressed as applied to unit of volume instead of weight. Since, however, the density varies with the temperature it is not possible to obtain a value that will apply other than approximately to more than one condition of temperature. A few of these values are given herewith :

SPECIFIC HEAT OF DRY AIR AT NORMAL PRESSURE.

TEMPERATURE. F.	WEIGHT OF 1 CU. FT.		SPECIFIC HEAT AT CONSTANT PRESSURE.	
	GRAINS.	LBS.	PER LB.	PER CU. FT.
0°	604.8	.0864	0.237	0.0205
32°	565.1	.0807	0.237	0.0191
62°	532.7	.0761	0.237	0.0180

In assuming temperatures for the purpose of working out an example we will cover a case involving freezing of the moisture, such as might apply to drying the air for blast furnaces, the maximum or temperature of inlet of air to be 80° F. and the minimum or outlet temperature of the air to be 20° F.

On the basis of .019 B. T. U. per cubic foot per degree, the heat required to be removed from 1000 cubic feet of air would be 1000 × .019 × (80 — 20) = 1150 B. T. U.

COOLING AQUEOUS VAPOR :—The rating for humidity and amount of moisture for unit of volume are obtained from readings of the hygrometer, employing a wet bulb and a dry bulb thermometer, and tables, such as are issued by the Weather Bureau.

We give values applying to the temperatures we have selected.

WEIGHT OF A CUBIC FOOT OF AQUEOUS VAPOR AT DIFFERENT TEMPERATURES AND PERCENTAGES OF SATURATION.

TEMPERATURE F.	PERCENTAGE OF SATURATION.			
	60 PER CENT.	70 PER CENT.	80 PER CENT.	100 PER CENT.
	grains.	grains.	grains.	grains.
0°	0.289	0.337	0.385	0.481
10°	0.466	0.543	0.621	0.776
20°	0.741	0.864	0.988	1 235
32°	1.268	1.479	1.690	2.113
62°	3.685	4.299	4.914	6.142
80°	6.560	7.654	8.747	10.934

In case we assume 70 per cent for condition of saturation at the higher temperature of 80° F. the moisture content would accordingly be 7.654 grains per cubic foot. At the lower temperature for saturation there would be remaining 0.776 grains. Consequently there would be eliminated per cubic foot $7.654 - 0.776 = 6.878$ grains or $1000 \times 6.878 = 6878$ grains or 0.982 lbs. per 1000 cubic feet of air.

The heat values representing the elimination of this moisture may be obtained as follows:

Removal of latent heat of liquefaction

$$0.982 \times 1000 = 982.0 \text{ B. T. U.}$$

Cooling from 80° to 32° F.

$$0.982 \times 1 \times (80 - 32) = 47.1 \text{ B. T. U.}$$

Freezing

$$0.982 \times 142 = 139.4 \text{ B. T. U.}$$

Cooling ice from 32° to 20° F.

$$0.982 \times 0.5 \times (32 - 20) = 5.9 \text{ B. T. U.}$$

1174.4 B. T. U.

This value is based on the following:

Latent heat of liquefaction . .	1000 B. T. U.
Latent heat of fusion	142 B. T. U.
Specific heat of water	1.00 B. T. U.
Specific heat of ice	0.50 B. T. U.

TOTAL FOR AIR AND VAPOR.

The total heat removed for cooling air and vapor for 1000 cubic feet of atmospheric air for the conditions mentioned would be obtained by adding the two values just obtained. From the value thus obtained and the value for the total amount of air involved it will be possible to obtain the value for the total quantity of heat to be removed.

In the case of a storage warehouse the total amount to be handled would of course depend upon the number of times the air was renewed in a given time, which ought in most cases to be as often as half a dozen times a day.

With the indirect air system the same air would be kept in circulation to a large extent. The heat to be supplied would

be that due to the differences in condition of the air sent out and returned from the cooling and drying apparatus, and making up for leakage.

In the case of a blast furnace the amount would be determined by the amount of oxygen required for combustion.

Auditorium-cooling would be to a considerable extent on the closed system. To avoid excess of humidity for comfort some of the returning warm air is by-passed and mixed with the cooled air.

For chocolate manufacture the conditions would correspond to a considerable extent to those for auditorium-cooling, with additional duty for cooling the product in process.

In any of these cases, with the limits of temperature and data as to humidity determined, the requirements from a refrigeration standpoint would be determined along the lines indicated above.

EFFECT OF LIGHTING AND INDIVIDUALS.

Features that have an important bearing on the heating and humidity of the air and in consequence upon the amount of refrigeration required for air-cooling are the effects produced by artificial illumination and the presence of human beings.

So far as lighting is concerned, the incandescent electric light is to be preferred from all standpoints. Among the reasons are small heat requirement per candle-power, immunity from detrimental effect on the atmosphere, both as regards humidity and vitiation, and in special cases, such as storage chambers, the facility with which it can be turned on and off from the outside, or at any convenient point.

The presence of a human being affects the temperature of the atmosphere by the heat given out; the humidity by moisture evaporated from the body and exhaled from the lungs; and the purity by the consumption of oxygen.

The effects of these various features can be approximated by the methods that have already been elaborated, with the help of data such as given below.

HEAT AND MOISTURE EFFECTS OF ILLUMINANTS.

The practical choice of illuminants in most cases narrows down to either gas or the incandescent electric lamp. Approximate values for heat effects of these are given below, together with the value for the wax candle for comparison.

HEAT EMISSION OF ILLUMINANTS.

Nature of Illuminant.	Heat Emitted Per Hour.
Gas light, ordinary	4000 B. T. U.
Wax candle	300 B. T. U.
Incandescent electric lamp, 16 candle-power	200 B. T. U.

Different authorities give values quite divergent for different illuminants. Those given above it is believed represent average normal conditions.

Values for ordinary gas-jets are given ranging from 10 to 17 candle-power, with gas consumption from 4 to 5.5 cubic feet per hour and heat values from 3500 to 4800 B. T. U. The latter value would seem rather high, as this would give a calorific value of over 800 B. T U. per cubic foot, whereas the value generally ranges from 650 to 700 B. T. U.

The table given below is based on an extensive table on illuminants of combustion, given by Dr. Louis Bell in "The Art of Illumination."

EFFECTS UPON THE AIR OF THE SPACE IN WHICH THEY ARE BURNED OF THE COMMON ILLUMINANTS OF COMBUSTION.

ILLUMINANT.	QUANTITY CONSUMED PER HOUR.		ILLUMINATION.	O REMOVED.	CO_2 PRODUCED.	MOISTURE PRODUCED.	HEAT PRODUCED.		VITIATION EQUAL TO ADULT PERSONS.
	GRAINS.	CU. FT.	CANDLE POWER.	CU. FT.	CU. FT.	CU. FT.	CALORIES.	B. T. U.	
Tallow candles.	2200		16	10.7	7.3	8.2	1400	5600	12.0
Sperm candles.	1740		16	9.6	6 5	6.5	1137	4548	11.0
Parafin oil.	992		16	6 2	4.5	3 5	1030	4120	7.5
Kerosene oil.	909		16	5.9	4.1	3.3	1030	4120	7.0
Coal gas, bat wing.		5.5	16	6.5	2.8	7 3	1194	4176	5.0
Coal gas, argand.		4 8	16	5.8	2.6	6.4	1240	4960	4.3
Coal gas, regenerative.		3.2	32	3.6	1.7	4.2	760	3040	2.8
Coal gas, Welsbach.		3.5	50	4.1	1.8	4.7	763	3050	3.0

Values for acetylene would approximate those for the Welsbach burner.

While the table given may not be strictly accurate, it is probably a fair representation of the relative conditions.

In general the vitiation of a tallow candle is considered to be equivalent to that of an adult human being.

For electric units, in addition to the incandescent lamp there are the Nernst lamp and the arc lamp. The conditions for any of these may be very much varied, so that it is not possible to give definite data applying to the same.

In the case of Nernst lamps, these are made up with glowers of different dimensions and with different numbers in a group. With arc lamps there are the direct current and alternating current, multiple and series, enclosed and open, all for various strengths of current.

An off-hand value for an arc lamp is 500 watts, which is equal to about $\frac{2}{3}$ horse-power or 1700 B. T. U. per hour.

An approximate table for electric illuminants is given herewith :

POWER CONSUMPTION OF ELECTRIC LAMPS.

KIND OF LAMP.	RATING.	WATTS.	B. T. U.
Incandescent, 16 c. p.	16 c. p.	50	170
Nernst, 6 glower, 400 c. p.	400 c. p.	520	1770
Enclosed arc, alternating current.	6 amp.	430	1460
Enclosed arc, direct current . . .	6 2 amp.	744	2520

Data in regard to high-class arc lighting with enclosed arc lamps equipped with proper deflectors and distributing devices are given in the table below. While with incandescent lamps the character and especially the color effect would be quite different, the actual power requirements for obtaining satisfactory results would be practically equivalent to those given in this table for enclosed arc lamps, based on 50-watt 16-candle-power lamps.

POWER CONSUMPTION FOR HIGH-CLASS ARC LIGHTING.

KIND OF SERVICE.	CONSUMPTION PER SQUARE FOOT.	
	WATTS.	B. T. U. PER HOUR.
Machine shop	.75 to 1.00	2.548 — 3.4
Ordinary store lighting	.75	2.548
Department stores	1 to 1.25	3.4 — 4.25
Mill lighting	1 to 1.3	3.4 — 4.42
General office	1.5	5.1
Drafting Room	1.75	5.95

EFFECT OF ADULT ON ATMOSPHERE.

The effect of the presence of a human being varies considerably for the same individual according to circumstances, as to whether at rest or in motion or working. For instance, the proportion of carbon dioxide exhaled during respiration may vary from 5 per cent. during sleep to 45 per cent. while at hard labor.

The quantity of heat allowed for an adult in auditorium is 100 calories or about 400 B. T. U. per hour. For persons at work the amount would be greater. A man employed at ordinary work for eight hours may work at a rate of about $\frac{1}{8}$ horse-power or 318 B. T. U. per hour. Evidently the rate for a man at work would be nearly double that while at rest.

As to moisture effect, a man exhales normally about 200 grains of water per hour and gives off by evaporation many times this amount.

As regards vitiation, the following table gives some data:

EFFECT OF RESPIRATION OF ADULT ON ATMOSPHERE.

	Per Hour.
Quantity respired,	15 cu. ft.
" vitiated,	73 "
" required, at $\frac{1}{1000}$ CO_2	930 "
Space required, ventilated,	800 "
Carbon dioxide produced,	500 grains.
Oxygen consumed,	415 "
Carbon consumed,	137 "
Water exhaled,	200 "

Approximate values that will answer in most cases for the effect of a human being on the atmosphere are given in the table below:

ALLOWANCES FOR EFFECT OF AN ADULT ON THE ATMOSPHERE.

Effect.	Allowance per hour.
Thermal—heat units emitted at rest	400 B. T. U.
Thermal—heat units emitted at work	800 B. T. U.
Humidity—moisture emitted	.25 lbs.
Vitiation—fresh air to be supplied	5000 cu. ft.

The data given will probably be of some assistance in the working out of the varied problems that may be involved in the subject of air-cooling, which is intimately involved in many industries, including ordinary refrigeration in warehouses, and cooling air for mines, auditoriums and special industries. Among the latter may be mentioned chocolate factories, which previous to the introduction of refrigerating apparatus were obliged to suspend operations during the summer season.

CHAPTER XII.

COOLING OF GOODS IN STORAGE.

THE amount of refrigeration required for the goods in storage is practically limited to the amount of heat involved in reducing the temperature of the goods from the temperature at which they are received to that of the storage space. After they have been once brought to this temperature, the refrigeration requirements are represented by the leakage through the walls of the chamber, and are consequently independent of the nature or quantity of goods in storage.

Consequently the refrigeration requirements for a given space would depend upon the rate of change in the interior contents. As the removal of heat is more or less gradual, extending over hours or even days in some cases, the refrigerating demands may assume a practically uniform rate, even with frequent and quite intermittent change of the goods in storage.

The actual amount of refrigeration required for products maintained above freezing is obtained from the weight, the range in temperature and the specific heat. For goods that are frozen it will be necessary to have data on weight, range in temperature above and below freezing, specific heat above and below freezing and latent heat for freezing.

Take the cases of curing of beef and freezing of chicken, the beef being brought to 34° F. and the chicken to 20° F. For beef the initial temperature would be about 98° F. on account of the animal heat.

The specific heat for beef is 0.77. For 10 tons of beef the refrigeration required would be:

$$10 \times 2000 \times 0.77 \times (98 - 34) = 989{,}600 \text{ B. T. U.}$$

As this refrigeration would be extended over 30 or 40 hours this value would represent about 30,000 B. T. U. per hour.

For the frozen chicken the values for specific heat are respectively 0.80 and 0.42 for above and below freezing and the

value for latent heat of freezing is 105 B. T. U. In this case we will assume an initial temperature of 80° F.

For 1 ton under the conditions given the heat to be extracted down to the freezing point is

$$2000 \times .80 \times (80 - 32) = 76{,}800 \text{ B. T. U.}$$

The latent heat involved is equal to

$$2000 \times 105 = 210{,}000 \text{ B. T. U.}$$

Below the freezing point the heat to be removed is

$$2000 \times .42 \times (32 - 20) = 10{,}080 \text{ B. T. U.}$$

The total heat to be extracted is accordingly the sum of these values

$$76{,}800 + 210{,}000 + 10{,}080 = 296{,}880 \text{ B. T. U.}$$

In another section will be found a compilation of temperatures for cold storage which will be found useful in this connection.

A table of data on specific and latent heat of food products that will serve as a basis for estimates on refrigeration requirements for goods is given herewith.

SPECIFIC AND LATENT HEAT OF VARIOUS FOOD PRODUCTS.

SUBSTANCE.	COMPOSITION.		SPECIFIC HEAT ABOVE FREEZING IN HEAT UNITS.	SPECIFIC HEAT BELOW FREEZING IN HEAT UNITS.	LATENT HEAT OF FREEZING IN HEAT UNITS.	
	WATER.	SOLIDS.				
Lean Beef..	72.00	28.00	0.77	0.41	102	The figures in the last column showing the latent heat of freezing have been obtained by multiplying the latent heat of freezing water, which is 142 heat units by a per cent. of water contained in the different materials considered, for as the solid constituents remain in their original condition, only the liquid or watery portion of these materials are concerned in the solidification or freezing of them.
Fat Beef...	51.00	49.00	.60	.34	72	
Veal.......	63 00	37.00	.70	.39	90	
Fat Pork ..	39 00	61.00	.51	.30	55	
Eggs	70.00	30.00	.76	.40	100	
Potatoes ...	74.00	26.00	.80	.42	105	
Cabbage ...	91.00	9.00	.93	.48	129	
Carrots	83.00	17.00	.87	.45	118	
Cream	59.25	30 75	.68	.38	84	
Milk	87.50	12.50	.90	.47	124	
Oysters	80.38	19.62	.84	.44	114	
Whitefish..	78.00	22.00	.82	.43	111	
Eels	62.07	37.93	.69	.38	38	
Lobster....	76.62	23.38	.81	.42	108	
Pigeon	72.40	27.60	.78	.41	102	
Chicken...	73.70	26.30	.80	.42	105	

In a general way the values given in the table below for the effective value of one ton of refrigeration will serve as a rough approximation.

EFFECTIVE VALUE OF ONE TON OF REFRIGERATION.

The following table gives approximately the space that can be cooled or the work that can be done per ton of refrigerating capacity per twenty-four hours continuous operation for plants of 50 tons capacity, with properly insulated spaces:

PACKING HOUSES.

10 beeves, approximate weight 7000 lbs., and needed space to hang same.
25 hogs, approximate weight 6000 lbs., and needed space to hang same.
60 calves, approximate weight 5200 lbs., and needed space to hang same.
75 sheep, approximate weight 5800 lbs., and needed space to hang same.

12,000 cubic feet curing space, temperature	40° F.
3,000 cubic feet freezer space, temperature	20° F.
1,500 cubic feet freezer space, temperature	0° F.

COLD STORAGE.

10,000 cubic feet of space (general storage), temperature	40° F.
6,000 cubic feet of space (egg storage), temperature	32° F.
3,000 cubic feet of space (butter storage), temperature	20° F.
2,000 cubic feet of space (game storage), temperature	10° F.
1,500 cubic feet of space (game storage), temperature	0° F.

BREWERIES.

8,000 cubic feet space (general space), temperature	30°–36° F.
40 barrels of beer wort, temperature limits from	70° to 40° F.

FOR SMALL PLANTS, HOTELS, RESTAURANTS, HOUSE AND MARKET BOXES.

500 to 2,000 cubic feet of space, temperature	35° F.

An allowance of storage floor space of one square yard will answer in general for each head of beef of from 650 to 750 pounds weight; for three sheep of about 80 pounds each; or for about 225 pounds of other meats.

CHAPTER XIII.

PIPING FOR REFRIGERATION.

To obtain the best economy and efficiency, there must be a general adaptation of all the parts of the system.

While, therefore, each feature of the system has a prominent bearing in obtaining the results desired, a proper arrangement of the piping of the refrigerator is of the utmost importance.

Results are not altogether to be governed alone by mechanical efficiency, that is, the relation between the refrigeration produced and the power applied. Other considerations frequently arise to influence the methods of operation. Were this not the case, the direct system would monopolize the field. Once the system has been decided upon, there arises the problem of the arrangement of the piping. The piping, as a rule, must be adapted especially for each individual case. A few general principles, however, can be laid out.

In the first place there should be a multiple system of piping. That is, the piping should be subdivided into comparatively short lengths, connected to headers for supply and exhaust, with a shut-off at each end. This affords some flexibility to the system in the way of regulation, by permitting the shutting off of individual sections in case the temperature tends to fall too low. Likewise, it permits of disconnection of individual sections for purposes of cleaning, without interrupting the refrigeration of the chamber.

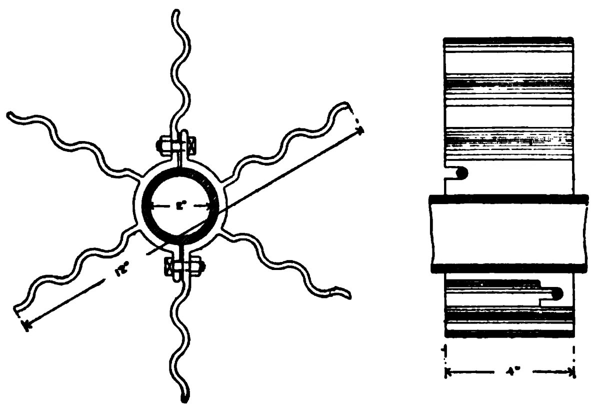
As regards the size of the pipe in general, the most economical results will be obtained by the use of the smallest size pipe practicable.

A free circulation of the air is indispensable to successful refrigeration. This may readily be attained by properly spacing the pipes, and avoiding any obstruction below the pipes that would tend to interfere with the circulation.

In case there is danger of damage to goods from the drip or moisture that may at times drop from the pipes, this danger may be averted by arranging the coils immediately over passage-ways or along the walls.

There is still, however, liability of trouble from so-called sweating ceilings, due to moisture collecting on the ceiling, and consequent liability to fall on the goods. When necessary to insure immunity from this evil, a protecting ceiling may be employed, connected to passage-ways or ducts at the sides, quite after the manner of many of the ordinary household refrigerators on the market.

FIG. 38.



F. W. Wolf Co.

RADIATING DISCS.

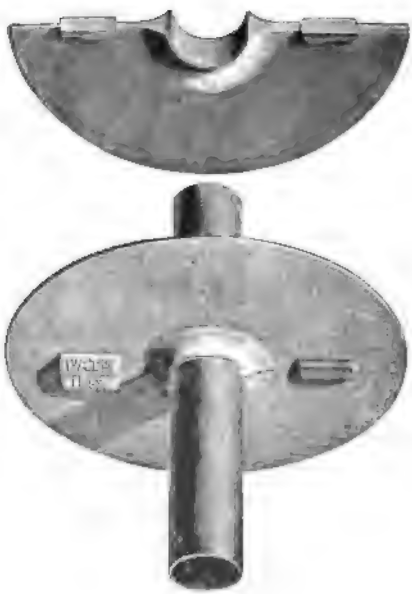
A method of increasing the radiating surface of pipe is by attaching discs of iron along its length, such as shown in Fig. 38 and Fig. 39. Whether this is good practice or not, there is some difference of opinion. The claim is made that better results would be obtained by putting in the additional amount of pipe called for by rejecting the discs. On the score of economy of installation, it may be said that the additional pipe called for would be less expensive than the discs. Neverthe-

less, they are used to a large extent, even though they cannot be considered as a necessity for successful refrigeration.

BRINE WALLS.

The brine wall is an example of a special method of application of the cooled brine for freezing and chilling of meat. These are made hollow, of steel plates, and placed parallel at

FIG. 39.



DISC FOR EXPANSION COILS. (De La Vergne Machine Co.)

short intervals from one another. The brine is circulated through the interior space of the plate. The meat to be frozen or chilled is hung in the passage-ways between the plates. The walls may of course be arranged horizontally instead of vertically.

PIPE.

As to whether pipe with lap-welded or butt-welded joints should be used, or whether bends should be made cold or hot, there are differences of opinion as well as practice. Some

prefer the smaller pipe on account of the better efficiency obtainable, in spite of the butt-weld, while others prefer to use two-inch pipe because it is lap-welded.

Extra-strong pipe is generally used, especially for the high-pressure section of the system.

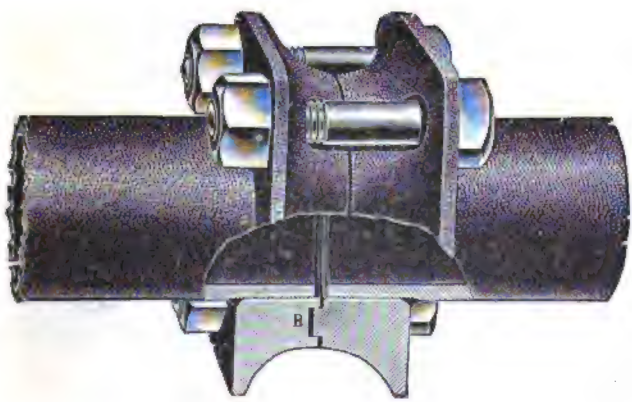
Galvanized pipe, though costing one-third more than plain pipe, generally pays for the extra cost in the end, especially for water pipe.

Straight wrought-iron pipe if obtainable is found to hold out better than pipe made of steel.

FLANGED JOINTS AND PIPE CONNECTIONS.

Flanged couplings or unions for connecting straight lengths of pipes to valves, return bends and fittings in general are

FIG. 40.



FLANGE COUPLING OR UNION.

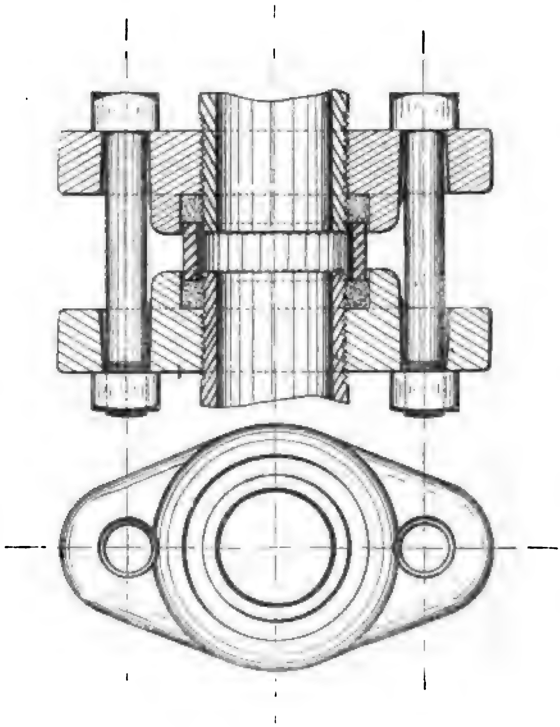
made with some form of recessed joint, packed with a rubber or lead gasket, the flanges being drawn together by clamping bolts. One style of joint is shown in Fig. 40, held together by four bolts. Similar joints are used for the fittings shown in Fig. 42, and Figs. 50, 51 and 52.

THE BOYLE PATENT UNION.

The Boyle patent union, Fig. 41, is of familiar design. One flange is screwed on the end of each pipe. Each has a

recess on the side of the joint immediately around the pipe for a ring of packing. Bearing against these rings of packing is a ring of metal or ferrule, ensuring with proper pressure the

FIG. 41.



BOYLE PATENT UNION.

tightness of the joint. This pressure is applied to the two bolts holding the flanges together. Other views of this union are shown in Figs. 47, 48 and 49.

SCREWED JOINTS.

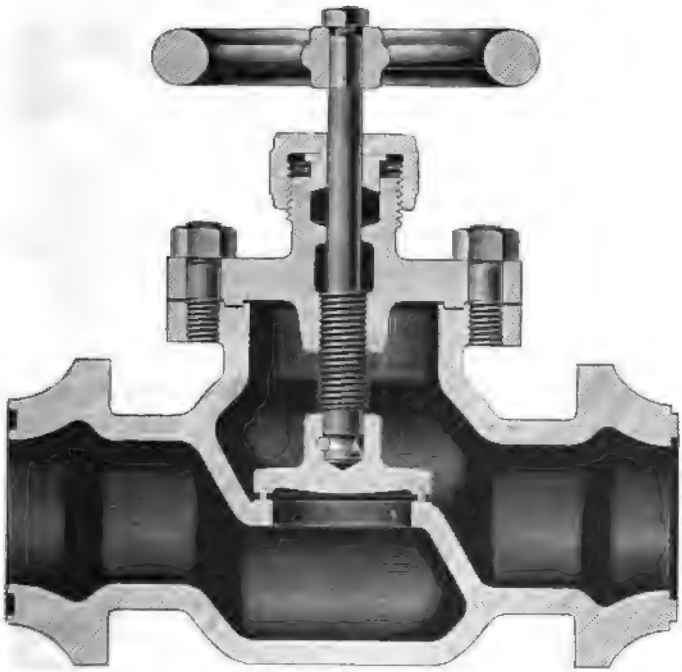
The screwed joint between the flange and pipe requires special attention to ensure tightness. One method that can hardly fail is to tap the flanges smaller than the pipe to which they are attached, the flange being expanded by heating and

screwed on while hot. With threads thoroughly tinned, and the recess between the back of the flange and pipe flushed with solder, a firm and reliable joint is made when cooled.

WELDED JOINTS.

Welded pipe-joints are made either by the electric welding process or by the use of thermit.

Fig. 42.



SECTIONAL VIEW OF GLOBE VALVE SHOWING SOFT-METAL SEAT.

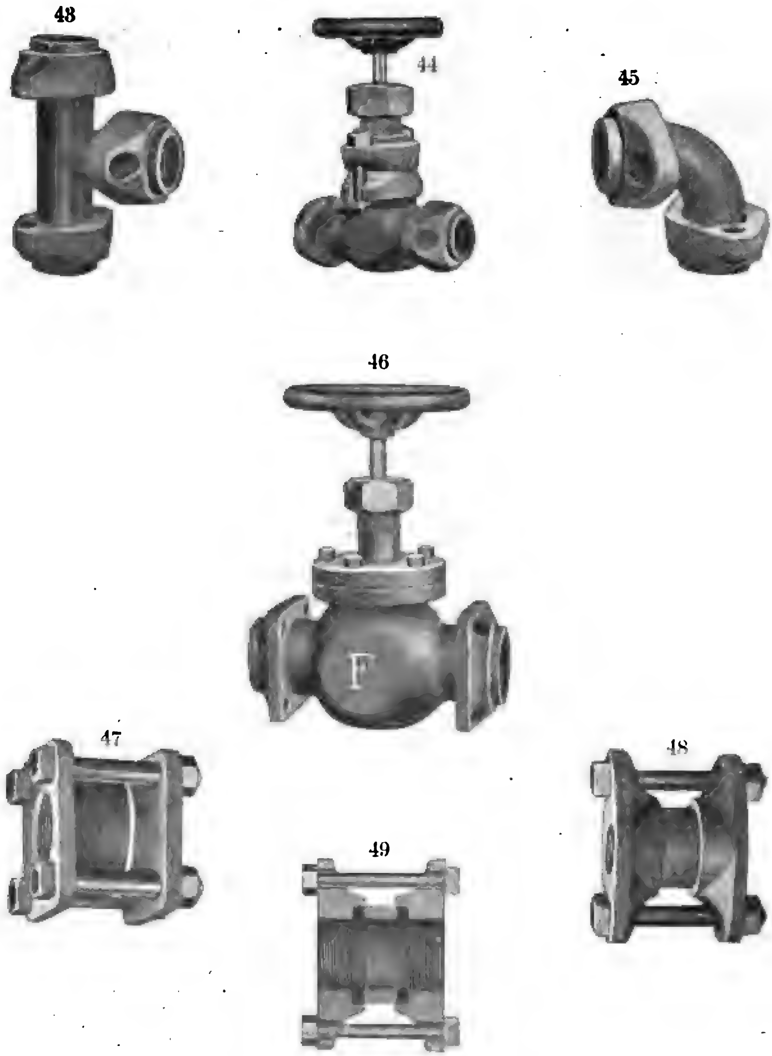
Electrically-welded joints are used by some manufacturers exclusively for making up pipe coils.

Thermit welds may be used in most any case, the limiting feature being that of cost. This class of joint has given good results in piping for pipe-line refrigeration. Generally, the thermit-welded joint will be the more economical for the smaller sizes, up to about 2″ pipe. For the larger sizes, joints with fittings will be the more economical.

COCKS AND VALVES.

Stop-cocks generally have one end provided with a cap over

FIGS. 43 TO 49 INCLUSIVE.



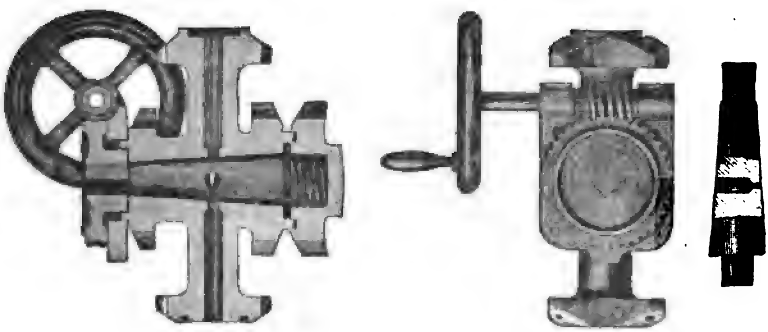
AMMONIA FLANGE FITTINGS ADAPTED TO "BOYLE" UNION.

one end of plug, and if for occasional use only, one over each

end, to prevent leakage. The cap is provided with a recessed joint, similar to that used with return bends and fittings. The plugs are kept on their seats by coil springs bearing against the cap at the large end of the plug.

These features are used in the expansion cock shown in Figs. 50, 51 and 52. This expansion cock is operated by a worm-wheel. To further facilitate a delicate adjustment, the cross-section of the opening for the admission is made tapering, opening from the point first.

FIG. 50. FIG. 51. FIG. 52.



EXPANSION COCK.

In the case of valves, the caps and removable plates or discs may have the recessed joint, as shown in Fig. 42 and Fig. 46, or the Boyle flange union as shown in Fig. 44. In either case the valve stem is provided with a stuffing-box, which requires careful packing and adjustment.

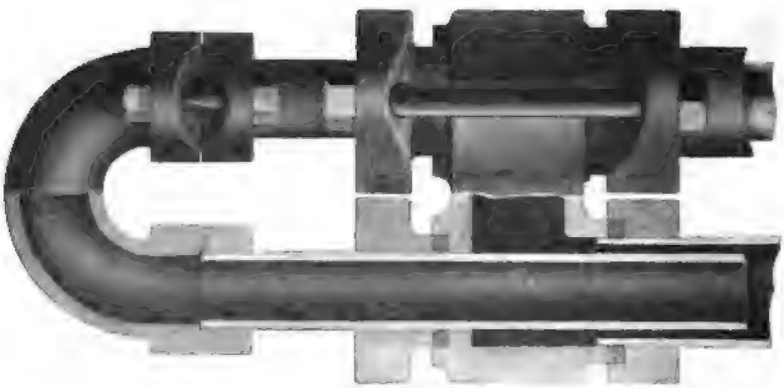
DOUBLE PIPE CONNECTIONS.

There is no questioning the fact that double-pipe construction involves considerable complication in structural details. That the issue has been successfully met is evidenced by the success and growing popularity of this class of structure and the various uses to which the same is applied. These uses now include steam condensers, ammonia condensers, liquid-ammonia coolers, brine coolers and distilled-water coolers.

In Fig. 53 is shown a view, part in section, of the Featherstone double-pipe connection. The construction of this double-

pipe return bend is shown clearly in the illustration. This style of return bend is used in connection with double-pipe brine coolers and double-pipe ammonia condensers. On the former the inner pipe is used for the circulation of the brine, while in the annular space between the pipes the ammonia is expanded. In double-pipe ammonia condensers the ammonia is circulated through the annular space between the pipes, the water being circulated through the inner pipe. It will be seen from the illustration that this construction permits the ready removal of any pipe without dismantling the other parts. The end connections and return bends are made of

FIG. 53.



FEATHERSTONE DOUBLE-PIPE CONNECTION. SECTIONAL VIEW OF RETURN BEND.

semi-steel and provided with oval flanges. End connections and companion flanges therefore are made to receive canvas-bound gum gaskets, joints being made by compressing the gaskets around the pipe and lip of fitting or flange by tightening of bolts. The return bend which connects the inner pipes in double-pipe return bends is also made with companion flanges provided with thin rubber gaskets.

TESTING PIPING.

It is customary to test all the parts that go into the system as well as the whole completed system. Some use hydrostatic

pressure for the parts, and others air pressure under water. The amount of pressure used ranges from 500 pounds to 1000 pounds. For testing a completed system, an air pressure of 300 pounds is commonly used. For testing a joint, a convenient method is to coat it with soap and water.

AMOUNT OF PIPING.

There is no question as to the importance of the subject of the amount of piping required for a specific amount of refrigeration. This is not determined solely from the refrigeration to be effected, but is closely involved in the other features of the system as well as in the condition in which the pipe itself is maintained. A coating of ice or snow on the outside of a pipe acts to a certain extent as an insulator, and a coating of slime, dirt, salt, or scale whether on the inside or outside is much worse. The decrease in efficiency of heat-transmission in boilers due to the accumulation of scale has been determined to be approximately as follows:

INCREASE IN FUEL CONSUMPTION OF STEAM BOILERS DUE TO ACCUMULATION OF SCALE.

Thickness of Scale.	Increase in Fuel Consumption.
$\frac{1}{64}$ inch.	2 per cent.
$\frac{1}{32}$ inch.	4 per cent.
$\frac{1}{16}$ inch.	9–13 per cent.
$\frac{1}{8}$ inch.	18–22 per cent.
$\frac{3}{16}$ inch.	27 per cent.
$\frac{1}{4}$ inch.	38 per cent.

A few rough-and-ready rules can be given that will serve for a crude approximation. The data given herewith will serve very well for such a purpose.

A basis sometimes used is to allow 300 feet of 1¼-inch pipe for one ton of refrigeration to maintain 4500 cubic feet of storage capacity at 32° F. to 35° F.

In one case of a small combination plant on shipboard required to produce one-half ton of ice per 24 hours and to maintain a storage room of dimensions $13' \times 16\frac{1}{2}' \times 7'$ high

at 36° F. the submerged condenser was equipped with 450 feet of 1-inch extra-strong pipe; the brine tank with 900 feet of similar pipe; and the cold-storage room with 300 feet of 1-inch galvanized iron pipe.

The triple-pipe brine cooler shown in Fig. 7 gives an effective heat-transmission of 80 B. T. U. per hour per square foot per degree F. difference in temperature.

A few general data on piping allowances are given herewith:

PIPING ALLOWANCES.

AMMONIA PIPING.

Service.	Pipe Surface.
Freezing tank, per ton ice,	100 square feet.
Brine tank, per ton refrigeration,	50 " "
Brine cooler, per ton refrigeration,	10 " "
Freezing chamber, per 1000 cubic feet,	350 " "
Storage room, per 1000 cubic feet.	35 " "

BRINE PIPING.

Skating rink, per 1000 square feet of ice surface,	800 square feet.
Freezing chamber, per 1000 cubic feet,	500 " "
Storage room, per 1000 cubic feet,	50 " "
Bunker room, per 1000 cubic feet,	20 " "

CHAPTER XIV.

WATER COOLING TOWERS.

THE operation of a refrigerating or ice-making plant demands a profuse use of water at as low temperature as obtainable for cooling and condensing. While in general this might imply a corresponding use of water in large quantities, as a matter of fact this is not always the case, as it is possible to reduce this quantity by as much as 90 per cent. by the installation of what is known as a water-cooling tower or gradirworks.

The function of the cooling tower is to cool water that has been used for condensing and cooling purposes so that it can be used again. This cooling is effected largely by means of evaporation of a portion of the water to be cooled. Accordingly the process naturally involves some loss of water. The greater the amount of water lost by evaporation the more the remaining unevaporated water will be reduced in temperature. This loss in water is found to be in general between 5 and 10 per cent.

PRINCIPLE OF OPERATION.

The principle involved in the operation of a cooling tower is to facilitate the exposure of a large surface of water to a large quantity of air. The ordinary methods of heat-transfer, radiation, conduction and convection, all have a favorable influence on the final result of reducing the temperature of the water. The greater amount of heat carried away, however, is by means of water vapor formed by evaporation of part of the water supplied. Every pound of water evaporated absorbs between 1000 and 1100 B. T. U.

EVAPORATION.

Evaporation takes place only from the surface of a liquid.

Air in contact with the surface of water may continue to remove moisture until it is laden to the point of saturation.

This point of saturation is a characteristic feature of water vapor, and depends upon the temperature. Evaporation would accordingly be facilitated

1. By exposing a large surface of water to contact with the air.

2. By bringing large quantities of air in contact with the surface of the water.

3. By supplying air low in saturation.

The first of these features is artificial. The second is natural in case natural wind-currents are depended upon and artificial where mechanical blowers are employed. These two features may be brought under control and constitute the basis of the art so far as the constructor and operator are concerned.

The third feature is within the province of the weather man, and must be taken as it comes.

The large surface of the water is obtained by spreading the water out as much as possible by feeding it at the top of the tower by means of troughs adapted to effect an efficient distribution and by retarding its progress downward as it falls by gravity.

The feature of bringing large quantities of air in contact with the surface of the water is effected by producing a circulation of air over the surface of the water. Natural draft and wind-currents with the help of suitable blinds and shutters may be utilized, but the most reliable and positive method is to use large blowers or ventilating fans. The efficiency is enhanced by taking advantage of the counter-current principle, the warm water being admitted at the top of the tower and the air supply at the bottom.

The degree of saturation of the atmosphere has an important bearing on the efficiency of a water-cooling tower. In the condition of saturation no moisture will be taken up. In case such atmosphere is heated, however, it is capable of taking up moisture until the condition of saturation is reached for the higher temperature. Accordingly, as the atmosphere in the upward passage became heated through contact with the warm descending water there would be effected some

evaporation and cooling on this account, though much less than would be produced under normal conditions.

METEOROLOGICAL CONDITIONS EFFECTING EVAPORATION.

The quantity of moisture contained in the atmosphere in the saturated condition depends upon the temperature. Corresponding to this temperature there is a definite pressure for the water vapor. Accordingly, a saturated atmosphere will contain a definite amount of moisture.

The relation between the quantity of moisture in saturated atmosphere and temperature, and other data pertaining to the same are shown in the accompanying table:

WEIGHT OF AIR, VAPOR OF WATER, AND SATURATED MIXTURES OF AIR AND VAPOR AT DIFFERENT TEMPERATURES UNDER THE ORDINARY ATMOSPHERIC PRESSURE OF 29.921 INCHES OF MERCURY.

Temperature Fareinheit.	Weight of a Cubic Foot of Dry Air at Different Temperature, in lbs.	Elastic Force of Vapor Inches of Mercury.	MIXTURE OF AIR SATURATED WITH VAPOR.				
			Elastic Force of the Air in Mixture of Air and Vapor. Inches of Mercury.	WEIGHT OF CUBIC FOOT OF THE MIXTURE OF AIR AND VAPOR.			Weight of Vapor Mixed with one Pound of Air in Pounds.
				Weight of the Air in Pounds.	Weight of the Vapor in Pounds.	Total Weight of Mixture in Pounds.	
0	.0864	.044	29.877	.0863	.000079	.086379	.00092
12	.0842	.074	29.849	.0840	.000130	.084130	.00155
22	.0824	.118	29.803	.0821	.000202	.082302	.00245
32	.0807	.181	29.740	.0802	.000304	.080504	.00379
42	.0791	.267	29.654	.0784	.000440	.078840	.00561
52	.0776	.388	29.533	.0766	.000627	.077227	.00819
62	.0761	.556	29.365	.0747	.000881	.075581	.01179
72	.0747	.785	29.136	.0727	.001221	.073921	.01680
82	.0733	1.092	28.829	.0706	.001667	.072267	.02361
92	.0720	1.501	28.420	.0684	.002250	.070717	.03289
102	.0707	2.036	27.885	.0659	.002997	.068897	.04547
112	.0694	2.731	27.190	.0631	.003946	.067046	.06253
122	.0682	3.621	26 300	.0599	.005142	.065042	.08584
132	.0671	4.752	25.169	.0564	.006639	.063039	.11771
142	.0660	6.165	23.756	.0524	.008473	.060873	.16170
152	.0649	7.930	21.991	.0477	.010716	.058416	.22465
162	.0638	10.099	19.822	.0423	.013415	.055715	.31713
172	.0628	12.758	17.163	.0360	.016682	.052682	.46338
182	.0618	15.960	13.961	.0288	.020536	.049336	.71300
192	.0609	19.828	10.093	.0205	.025142	.045644	1.22643
202	.0600	24.450	5.471	.0109	.030545	.041445	2.80230
212	.0591	29.921	0.000	.0000	.036820	.036820	Infinite

Below saturation there would be a smaller amount of water vapor in the atmosphere with a proportionate reduction in the vapor pressure. The term absolute humidity is applied to the actual quantity of moisture in grains contained in a cubic foot of atmosphere. The percentage value of the absolute

FIG. 54.

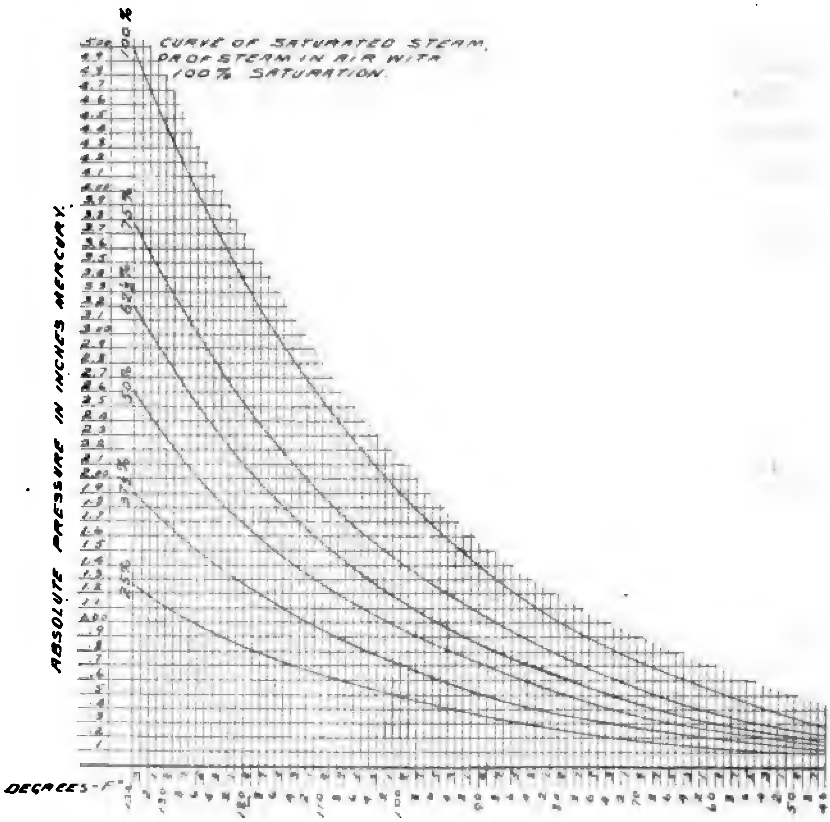


CHART SHOWING VAPOR PRESSURES FOR DIFFERENT TEMPERATURES AND DIFFERENT DEGREES OF SATURATION.

humidity to the maximum at saturation is called the relative humidity.

The chart shown in Fig. 54 gives values for vapor pressures for different temperatures and different degrees of saturation.

The corresponding weight of moisture in grains per cubic foot is given in the chart shown in Fig. 55. From the curves

Fig. 55.

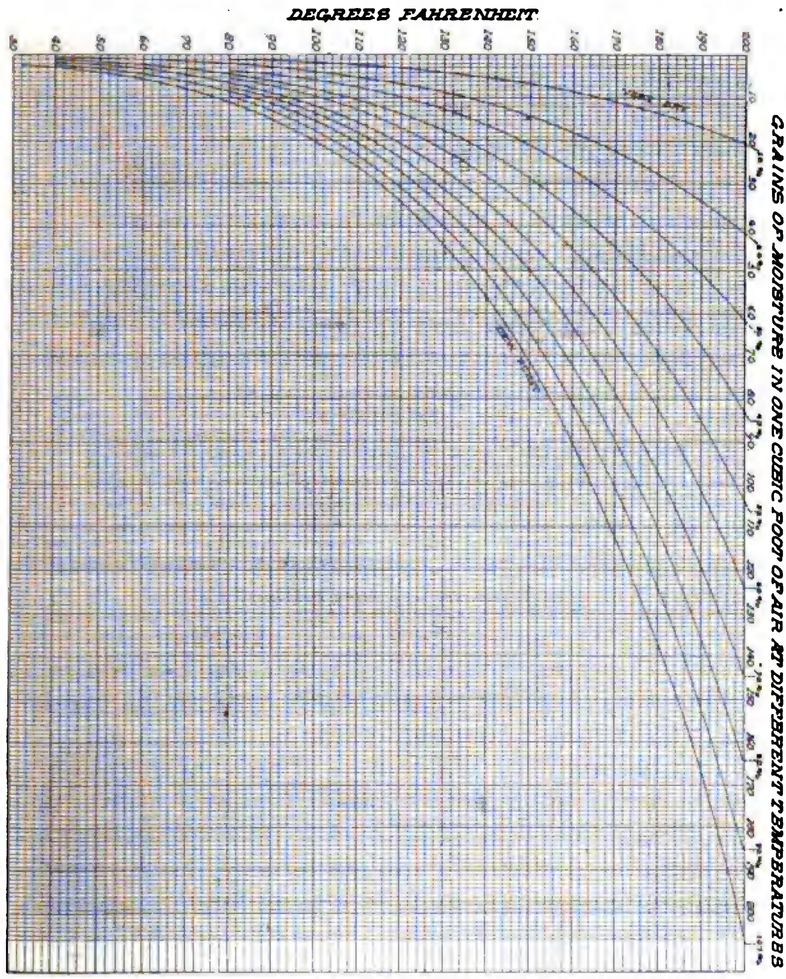


CHART SHOWING RELATION BETWEEN RELATIVE HUMIDITY AND ABSOLUTE HUMIDITY FOR DIFFERENT TEMPERATURES.

for relative humidity and the temperature the value for absolute humidity may be obtained.

The rate of evaporation from the surface of water is ex-

pressed in a formula determined by Mr. Desmond FitzGerald, which has been favorably considered by the Weather Bureau, as follows:

$$E = 0.0166\,(e_s - e_d)\left(1 - \frac{v}{2}\right)$$

in which E = evaporation in inches per hour.

e_s = vapor pressure in inches corresponding to the surface temperature of the water.

e_d = vapor pressure corresponding to the dew-point.

v = wind velocity in miles per hour.

The values for vapor pressure are obtained by means of the wet and dry bulb thermometers and the usual tables issued by the Weather Bureau.

An inspection of the formulas shows that, at the saturation point, with $e_s = e_d$, the evaporation or $E = 0$.

FEATURES OF CONSTRUCTION AND OPERATION.

A few features of construction may well receive some attention.

TOWER-STRUCTURE:—As applied to the exterior shell the tower may be constructed of brick, steel or wood.

COOLING-SURFACES:—These form the interior of the structure and are made of iron, glazed tile or wood, arranged so that the water fed at the top will spread out and be retarded in its progress as it trickles downward.

WATER-DISTRIBUTING APPARATUS:—This represents the contrivance for the simple but important feature of distributing the water at the top of the tower. For this purpose are used pipes with slots, perforated pipes, and galvanized iron troughs.

FANS:—These are arranged at the base of the tower. Sometimes only one fan is used for a tower, while there are those who advocate the use to two fans to a tower.

WATER-BASIN:—The basin beneath the tower which catches the cooled water and from which it is led to the condensers is, according to the location of the tower, either built of concrete or bricks, or consists of a steel pan of adequate size and depth. In either case it should be so constructed that a ready separa-

tion of the impurities from the water may be effected by precipitation and drawing off at the bottom, the water supply being drawn from a level somewhat above the bottom.

LOCATION:—The desirable location for a cooling-tower is above the condensers, so that the water will flow to the latter by gravity. If necessary the tower can be used successfully in other locations.

CAPACITY:—Cooling-towers are built with capacities of from 50,000 to 1,000,000 gallons per diem.

WEIGHT:—The matter of weight is closely involved with nearly every other feature. For a given capacity a wooden structure would be the lightest, and on this account alone, aside from other advantages claimed, would be inclined to demand favor, especially for locations at an elevation.

PUMPS.

Claims are made that the power required to pump the water the height of the tower is about one-half horse-power per 100,000 gallons per diem. Ordinary water pumps are used, such as would probably be required for other purposes in case there were no cooling tower.

RESULTS OBTAINED.

A few results that have actually been obtained in practice are given herewith.

RESULTS OBTAINED WITH WATER-COOLING TOWER.

Temperature of Air in Shade.	Humidity of Air.	Temperature of Hot Water.	Temperature of Cooled Water.
100 Deg. F.	25–50 %	110 to 135 Deg. F.	71–83 Deg. F.
95 Deg. F.	25–50 %	110 to 135 Deg. F.	69–80 Deg. F.
90 Deg. F.	25–50 %	110 to 135 Deg. F.	66–76 Deg. F.
85 Deg. F.	25–50 %	110 to 135 Deg. F.	64–73 Deg. F.
80 Deg. F.	25–50 %	110 to 135 Deg. F.	62–69 Deg. F.

It is claimed that water can be cooled in the hottest summer months from 1° to 25° F. below the temperature of the atmosphere, according to the percentage of moisture contained therein.

CALCULATIONS FOR EVAPORATION.

Assume an atmospheric temperature of 80° F. and 50 per cent. relative humidity. The vapor pressure for these conditions would be about 0.5 inches of mercury. The temperature for saturation with this pressure is about 58.5° F., which would be the actual low limit of temperature for cooling. Allowing for practical operations a difference of 0.2 inch of mercury between the vapor pressure for the water surface and the atmosphere to secure evaporation the practical low limit of temperature for the water would correspond to a pressure of $0.2 + 0.5 = 0.7$ inches of mercury, which is about 69° F.

To cool 1000 pounds of water from 129° F. to 69° F. would require

$$1000 \times (129 - 69) = 60{,}000 \text{ B. T. U.}$$

This would require the evaporation of about $\frac{60{,}000}{1000} = 60$ lbs. of water, which is equivalent to 6 per cent. of the total.

The atmosphere at 80° F. and 50 per cent. humidity contains 5.467 grains of moisture per cubic foot and at 69° F. and saturation the amount would be 7.726 grains per cubic foot. The amount absorbed per cubic foot of air would be the difference between these two values or $7.726 - 5.467 = 2.259$ grains per cubic foot, which is equivalent to 0.0003277 pounds. Accordingly the quantity of air required would be $\frac{60}{0.0003277} = 184{,}000$ cubic feet.

COST OF COOLING TOWER.

Take the case of a 100-ton refrigerating plant on a liberal basis of 2 gallons of water per minute per ton the number of gallons of water required per day would be: $200 \times 1440 =$ 288,000 gallons per day.

This would require a fan of 9 feet diameter, making 190 revolutions per minute and requiring 12 horse-power to drive.

The cost of the outfit will be in the neighborhood of $2,000.00. The loss of water by evaporation at 5 per cent. would be 14,400 gallons per day.

For the 12 horse-power, if a small engine is used for driving the fan, there will be required about 72 pounds of coal per hour.

In case the tower is erected on the roof, so that the water runs by gravity to the ammonia condensers, the pumping will be limited to the lift, corresponding to the height of the tower. In cases where without the cooling tower the water would be pumped from a well, the pumping requirements for the tower would be off-set by the saving in pumping from the well.

Another feature involved in the cost is the life of the tower. The only parts subject to wear and tear are the pump and fan, which involve the usual small amount of attention generally devoted to such apparatus.

From the crude data given it is possible to determine in an off-hand manner as to whether or not it will pay to install a cooling tower.

It will generally be found that where water is comparatively scarce or expensive, due either to the well supply being insufficient or to being limited to use of city water, a cooling tower will prove a boon that will relieve the situation. Furthermore, there are actually very few cases in which such a tower would not afford a reduction in cost of operation and pay for itself in a short time.

CHAPTER XV.

GENERAL DESCRIPTION OF A COMPRESSED AIR REFRIGERATING PLANT.

Among the earliest efforts in the way of building refrigerating machines, the air machine will be found to have a prominent place.

An explanation of the refrigeration effect of compressed air is as follows:

Air being an elastic fluid, it is subjected to a heavy pressure and compressed into cylinders as shown in Fig. 56.

A = Steam Cylinder.
C = Air Compressor.
D = Cooling Coil.
E = Oiling Interceptor.
F = Expanding Cylinder.
G = Circulating Coil.

The air is taken into cylinder "C" or the compression cylinder from coil "G" which is used for the circulation of the cooled air.

By passing the air through the compressing cylinder it is compressed into a density of ten or fifteen atmospheres.

The heat held in specific form is intensified from 75 degrees in its original form to 300 or 400 degrees in a compressed condition.

This heat is conducted off by the compressed air being held in a coil surrounded by water or in long pipes passing through the atmosphere, as when used for rock-drilling appliances.

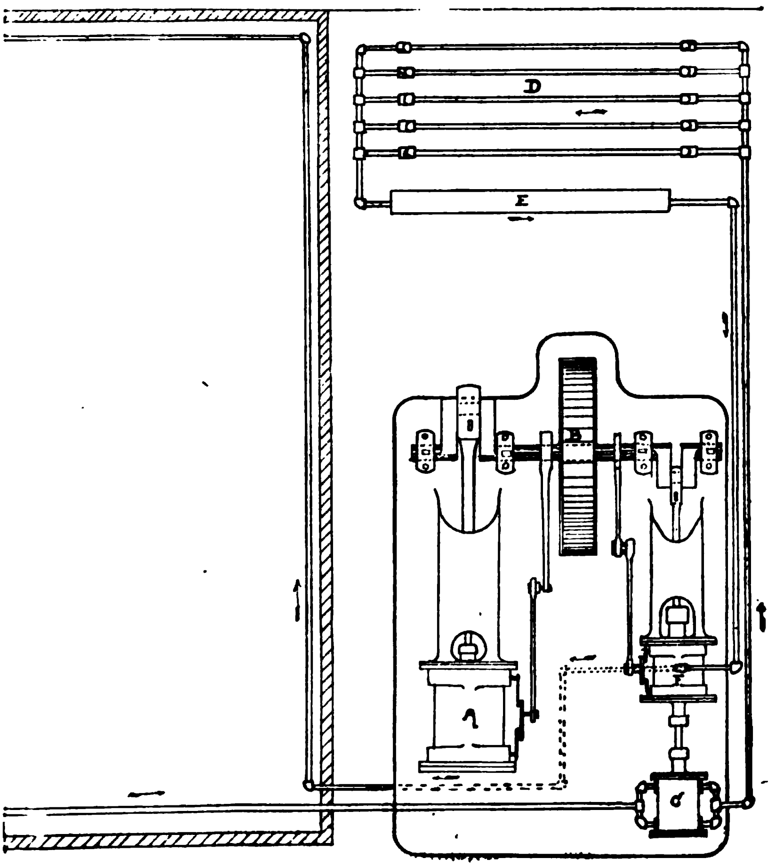
When the temperature of the compressed air has become reduced by conduction to its normal temperature of 75° it is still compressed to 15 atmospheres.

Should this be allowed to escape into the atmosphere at this point, a temperature of from 10° above zero to zero would

be obtained, part of this low temperature being due to the energy required to force itself into the atmosphere against atmospheric pressure 14.7 lbs. per square inch.

Should the compressed air be allowed to expand into a

FIG. 56.



COMPRESSED AIR REFRIGERATING PLANT.

chamber in which there was a vacuum, the result would be a higher temperature.

We have still another action for the air, which is its passage through the expanding cylinder.

This cylinder has a cut-off valve motion, and the air entering at, say 150 pounds pressure, aids the steam cylinder in its work.

Here is demonstrated the fundamental law, that all motion or power exerted is actuated solely by heat, for the air in expanding in the cylinder has consumed the heat until it is delivered into the cooling coils at from 40 to 70 degrees below zero.

An inquiring mind might ask, "What becomes of the heat as it passes through the expanding chamber?" and as we have as a result energy, as shown in the cylinders of a compressed air rock drill, and as it seems impossible to determine the dividing point between energy and heat, it may not be far out of the way to claim they are one and the same thing.

The system thus briefly described using cooling coils or circulating coils for the transmission of the refrigerated air to the refrigerating chambers is known as a closed system.

The system used at one time rather extensively on shipboard was the open system in which the pipe coils G were dispensed with. The distribution of the refrigerated air in this case was effected by means of large trunk-ways, being discharged directly into the refrigerating chambers by the delivery trunk and drawn from the return trunk by the air compressor.

Apparatus for either of these methods is bulky and inefficient for the duty performed. An improvement of considerable merit is the use of the closed system with air compressed to several times the density of normal atmospheric pressure for the basis of the system, the air supplied to the compressor being brought to this pressure by an auxiliary priming pump.

In cases where exceedingly low temperatures may be wanted for special purposes with efficiency of comparatively secondary importance the compressed-air system will be found to be generally quite reliable and well suited to the purpose.

CHAPTER XVI.

FEATURES COMMON TO THE AMMONIA ABSORPTION AND COMPRESSION SYSTEMS.

As has already been stated in Chapter II there are certain features that are common to both the ammonia absorption and compression systems and others that are peculiar to each. In the present case we will consider some of the features that are common to both.

AMMONIA CONDENSER.

Extended reference has been made to this in the special chapter on condensers, Chapter VIII.

PURGE COCK OR AIR VALVE.

This is a cock or valve provided at the highest point of the system for blowing off air or accumulated foreign gases. In some cases a small pet cock for this purpose is located at the top of each condenser coil.

LIQUID AMMONIA RECEIVER.

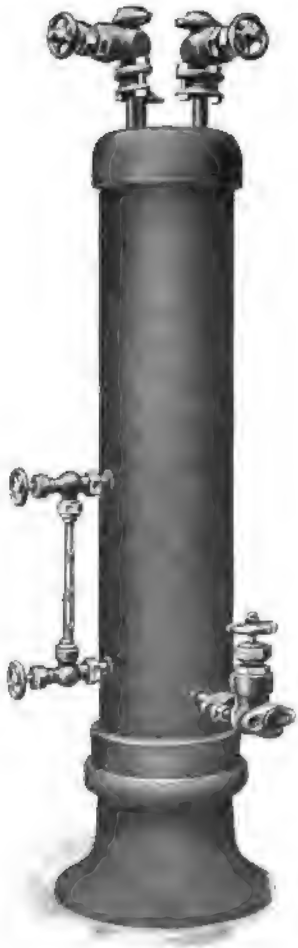
This feature serves as a storage tank for liquid ammonia received from the condenser before admission to the expansion valve. The receiver should be amply large to store the entire charge of ammonia in case of emergency and should be strong enough to withstand high pressures, as it is of course part of the high pressure system. Gauge glasses are provided and gauge cocks that close automatically in case of breakage of the gauge glass. They are almost invariably built of a cylindrical shell type, in some cases arranged horizontally and in others vertically. One of the vertical type is shown in Fig. 58.

LIQUID FORE COOLER.

The function of the liquid fore cooler is to cool the liquid en route from the condenser to the receiver. It is not an in-

dispensable feature but is one of the refinements that finds a place in an up-to-date plant where only the best possible efficiency and economy will be acceptable. It is a means of ob-

FIG. 58.



LIQUID AMMONIA RECEIVER.

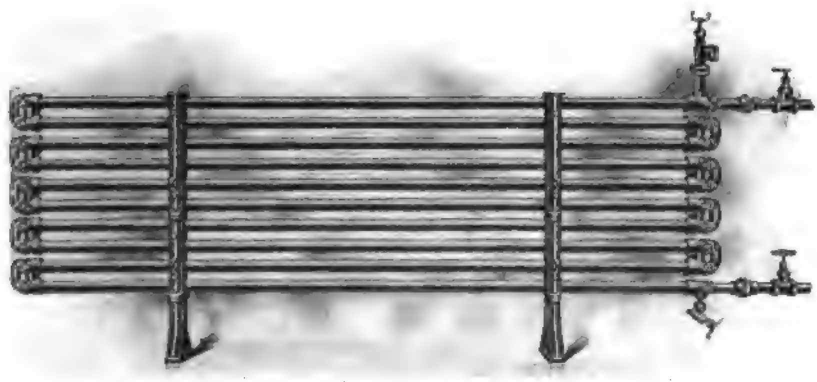
taining the best results from the available water supply. In some cases it may be combined with the condenser, as shown in Fig. 34, or it may be installed as a separate apparatus. In

Fig. 59 is shown a double-pipe liquid ammonia cooler. The cooling water en route to the condenser passes through the annular space between the outer pipe and the inner pipe conveying the liquid ammonia.

EXPANSION COCK OR VALVE.

The expansion cock or expansion valve is an important feature. It should be adapted to obtaining close refinement of regulations. Good results are obtained with what is known

FIG. 59.



DOUBLE-PIPE LIQUID AMMONIA COOLER.

as a needle valve. A special form of expansion cock is shown in Figs. 50, 51 and 52.

EXPANSION COILS.

These are the coils into which the liquid ammonia is admitted from the expansion valve and in which the vaporization of the liquid occurs, resulting in the cooling desired. These coils may be located in the refrigerating or freezing chambers; in a brine tank or freezing tank; in a bunker room for cooling air; or may be part of a double-pipe brine cooler.

STEAM BOILER PLANT.

While the steam boiler plant would not be identical for the

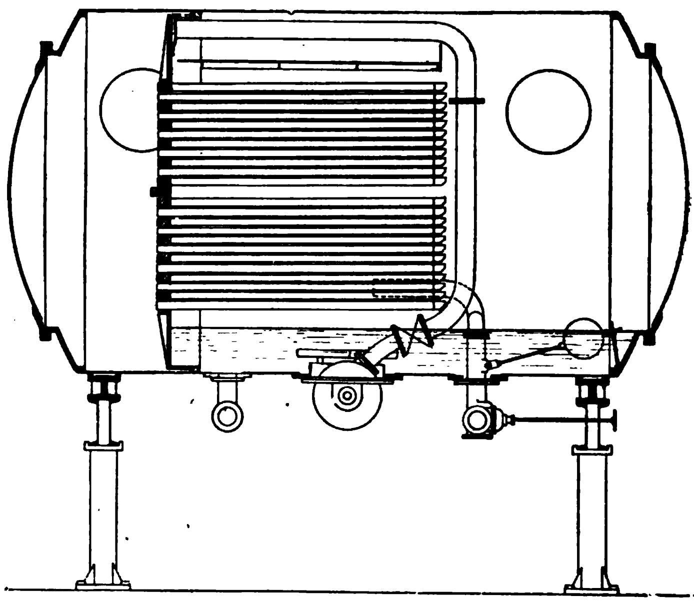
two systems, the style of boilers and feed pumps would be similar to those for steam power plant.

EVAPORATOR.

This is an apparatus that would be used only in special cases, as for obtaining fresh water from sea water by distillation. In Fig. 60 is shown a sectional view of an apparatus of this class known as the Lillie evaporator. It is of the class of apparatus used in sugar production designed to effect evaporation under partial vacuum.

The apparatus consists of a cast-iron shell provided with a

FIG. 60.



THE "LILLIE" EVAPORATOR.

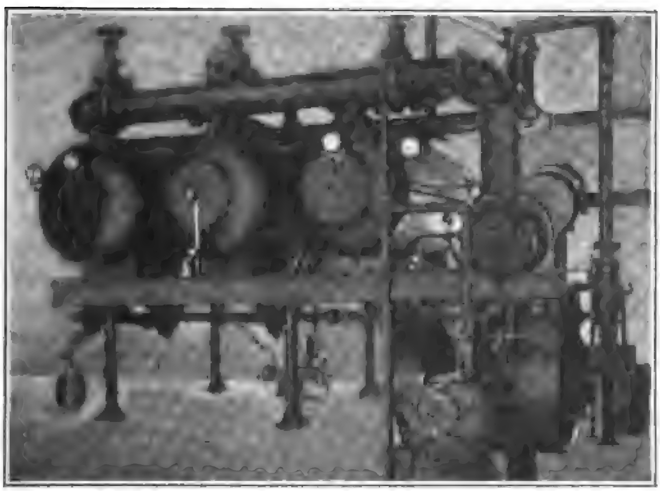
system of copper tubes. Near one end is a head tube which divides the evaporator into two parts, one called the steam space, shown at the left in Fig. 60, the other the vapor space, shown at the right in the illustration.

One end of each copper tube is expanded in the tube head,

the other end of the tube being closed, except that the extreme end is provided with a small air vent hole. Under the evaporator a centrifugal pump is placed which serves to circulate the water over the tubes. A float in the float-box keeps the water at a predetermined level, which level can be observed by the glass gauge on the float-box.

The steam supplied to the steam-space is condensed, the water formed being delivered to the condenser. The water vapor is formed as stated under partial vacuum, and consequently at low temperature, the vacuum being maintained by

FIG. 61.



TRIPLE EFFECT LILLIE EVAPORATOR FOR DISTILLATION OF SEA WATER.

an air pump. From the evaporator the vapor is delivered to the vapor or steam condenser, where it is condensed in the usual way. Improvement in economy is obtained by increasing the number of evaporators in series, so as to obtain more nearly the full effect of the heat of the steam.

A view of a triple effect evaporator used to obtain fresh water from sea water in an ice plant at Key West, Florida, is shown in Fig. 61.

CHAPTER XXII.

FEATURES OF THE ABSORPTION SYSTEM.

There are a few special characteristic features of the Ammonia Absorption System that call for special reference.

A particularly important part is the distilling apparatus or the still. This consists of a number of different elements. Sometimes the still is considered as including a generator, analyzer, rectifier and heater. The latter is also known as heat exchanger, economizer, and as equalizer. We will consider these individually.

THE GENERATOR.

The generator or retort in the Absorption System is the apparatus in which the anhydrous ammonia is generated. The process involved consists in driving the anhydrous ammonia or ammonia vapor from the aqua ammonia by heat. The essential feature then is a chamber for the aqua ammonia, arranged so that it can be subjected to heat. Suitable outlets should be provided for the ammonia vapor that is generated, and for drawing off the weak solution or weak liquid that remains.

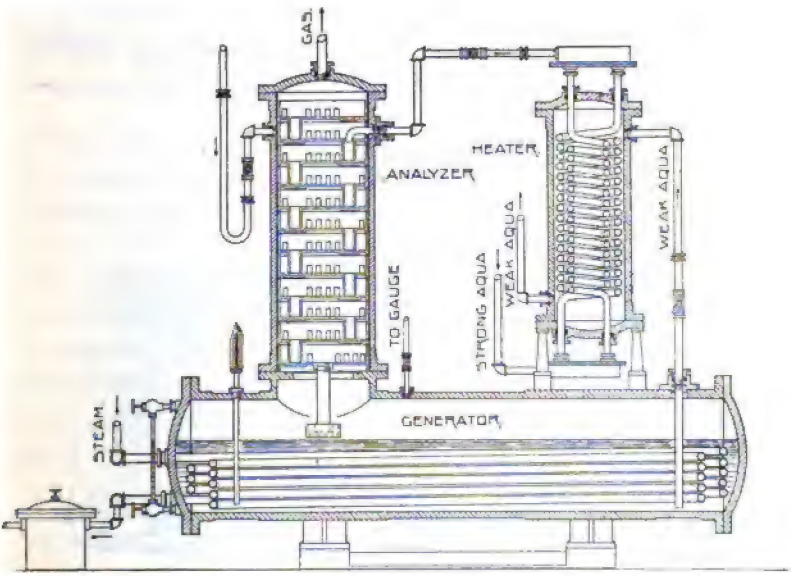
In practice the heat is supplied by steam coils in the chamber with the aqua ammonia. The operation of the generator may be improved by having a succession of these chambers, one below the other, the strongest solution being fed into the uppermost. As the solution passes down in consecutive order through the chambers below, it gradually becomes weaker, until upon leaving the lower chamber it is weak enough to be drawn off to the weak liquid tank.

A generator made with a single shell is shown in Fig. 62.

THE ANALYZER.

This apparatus generally consists of a series of baffle plates or separating pans located in a stand-pipe on top of the generator, as shown in Fig. 62. The top serves as the outlet for the ammonia vapor and inlet for the strong aqua ammonia, the vapor being delivered from the extreme top and the aqua

FIG. 62.



THE POLAR STILL.
Sectional View of Generator, Analyzer and Heater.

admitted to the uppermost suspension pan. The aqua as it trickles downward over the series of pans and the vapor in its winding passage upward become considerably intermingled with the result that the vapor is largely freed from water in suspension and becomes nearly anhydrous.

THE RECTIFIER.

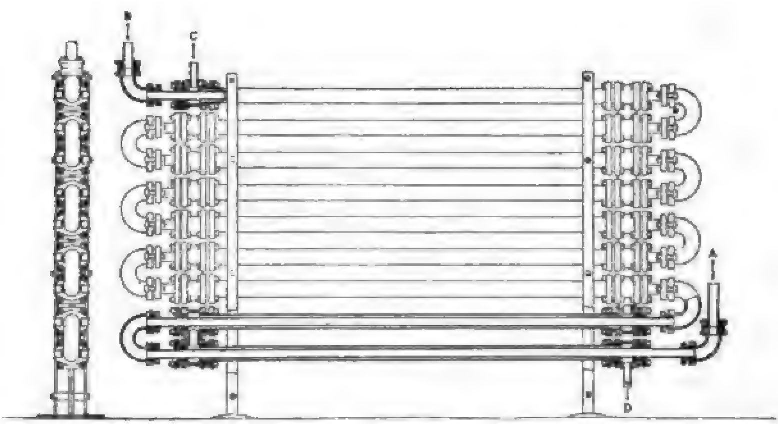
The function of the rectifier is to render the vapor practically anhydrous by removing the remaining water. This

consists of a suitable chamber with a net-work of vertical tubes. The vapor is admitted to the shell of the chamber, the liquid falling to the bottom and is led back to the generator. The pipes may contain cooling liquid. A satisfactory arrangement is to pass through these pipes the strong aqua ammonia on the way to the analyzer.

THE EQUALIZER.

One of the economic features of the absorption system is the equalizer. It is designed to effect a transfer of heat from the weak liquor from the generator to the strong liquor en route to the generator.

FIG. 63.



THE EQUALIZER.
Vogt, double-pipe construction, absorption system.

The two liquors are passed through separate coils in close proximity to one another, as in Fig. 62, or may be one enclosed within the other on the double-pipe principle, as shown in Fig. 63. The weak liquor, as it leaves the generator, contains an excess of heat which it is advantageous to dispose of before it reaches the absorber. On the contrary, in the case of the strong liquor which is pumped from the absorber to the generator, these conditions are exactly reversed. In the absorber the temperature is maintained low, while in the gener-

ator the contrary is the case. Accordingly, a transfer of heat en route, as mentioned, is a distinct gain.

THE WEAK LIQUOR COOLER.

A weak liquor cooler is sometimes used, built after the plan of a condenser. Its purpose is to remove heat from the weak liquor on the way from the generator to the absorber. The proper location for it is below the regular condenser, so as to allow the use of the condenser water to effect the desired cooling.

THE AMMONIA PUMP.

The distinctive feature of the ammonia pump in the absorption system lies in the fact that it is the only mechanically operating part of the plant aside from a feed pump for the boiler. The pump, however, is not an ordinary affair, as it must involve special features to avoid loss of ammonia under the comparatively high pressure. Especially is this the case in regard to the stuffing-box. The problem, however, is considerably minimized by the fact that the pump is a comparatively small affair, and may be designed to run at moderate speed.

AUTOMATIC REGULATOR.

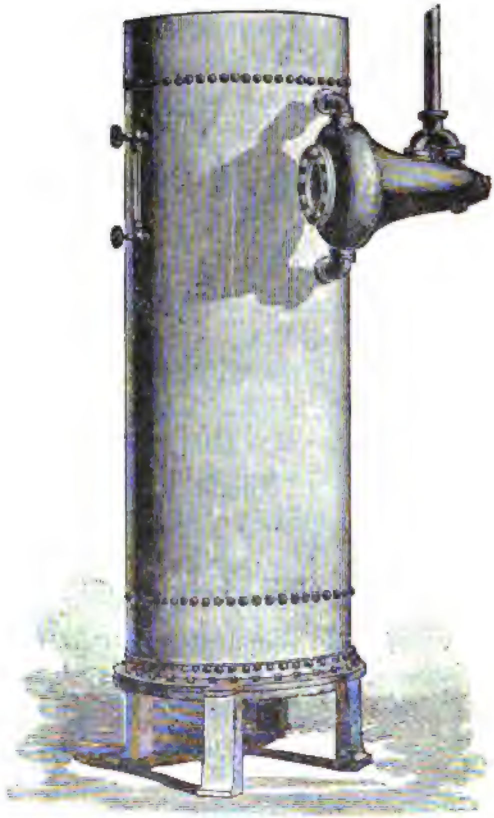
This serves to regulate the flow of weak liquor to the absorber. It operates to maintain the supply of weak liquor to correspond with the rate at which the aqua ammonia pump carries away the strong aqua ammonia.

THE ABSORBER.

In the absorber the process takes place which gives the name to the system, namely, the absorption of ammonia vapor by water or weak aqua ammonia. See Fig. 64. The duty of the absorber is accordingly the reverse of the duty of the generator. As the process of separation in the generator is brought about by the supplying of heat, so in the absorber the process is assisted by the removal of heat. The absorber

is accordingly provided with cooling coils with a flow of water to reduce the temperature of the contents. The weak liquor is supplied from the weak liquor tank, and the ammonia vapor is drawn from the refrigerating coils. It is accordingly the duty of the absorber to regulate the back pressure in the refrigerating coils.

FIG. 64.



THE ABSORBER

The strong aqua ammonia that is formed in the absorber is either pumped from the absorber directly to the generator through the equalizer, or is drawn off into a separate tank from which the supply for the generator is drawn.

CHAPTER XVIII.

FEATURES OF THE AMMONIA COMPRESSION SYSTEM.

As such features as are common to both the ammonia absorption system and the ammonia compression system have been already considered in Chapter XVI, we will consider herewith only such features as are characteristic of the ammonia compression system.

MOTIVE POWER.

Although a small amount of motive power is required in the ammonia absorption system to operate the pump for delivering the strong aqua ammonia to the generator, this is such a diminutive affair that it is not to be considered in connection with the compression system, in which mechanical power is depended upon entirely to bring the refrigerant to the higher temperature, so that the condenser water can perform its function of carrying off the heat corresponding to the refrigerating duty. Accordingly, the motive power constitutes one of the most important features of a compression plant.

The matter of choice of motive power is, however, not particularly involved in the compressor, as any kind of power will generally answer, the choice being determined from local conditions.

Although use is occasionally made of water power, electric power, or gas or gasoline, the large majority of plants are operated by steam.

STEAM ENGINES.

Although the details of the steam engine are more or less intimately involved with those of the compressor, the two in most cases being made up practically as one unit, the engine problems are common to those of steam engines in general.

All kinds of engines are used, and all kinds of results are obtained. In a strictly refrigerating plant a first-class engine has the same advantages as in any manufacturing plant. In the case of a can-ice plant, however, this does not so clearly hold true, because the exhaust steam is used for the production of ice and in most cases is not quite equal to the demand, so that the deficiency must be made up by live steam from the boiler. Accordingly, economy must be looked for in the boiler rather than in the engine.

It is possible, however, by the use of an auxiliary apparatus known as an evaporator to obtain full benefit of the economy of a first-class compound condensing steam engine in an ice plant and increase the production of ice per ton of coal over 25 per cent. This apparatus is used to evaporate water by utilizing the heat in exhaust steam, the apparatus operating under high degree of vacuum.

Where the compressor is belt driven, or in general where the engine is used for other purposes than driving the compressor, the design of the engine is quite independent of the compressor. The case is different, however, where the engine and compressor are more or less intimately connected, as where they are either directly connected by cranks to the same shaft or arranged tandem. In either of these cases the speed of the engine and that of the compressor are obviously the same, which is generally somewhat slower than would ordinarily be the case with engines of equivalent power.

With the tandem arrangement both the speed and the stroke are identical. This results in a rather large ratio of cylinder diameter to length of stroke. Furthermore, this method of drive is undesirable from the fact that the greatest strain on the compressor is exerted at the extreme end of the compression stroke, at which point the effort of the engine is a minimum, necessitating, accordingly, unusual dependence upon the fly-wheel for the delivery of stored-up energy.

EVAPORATOR.

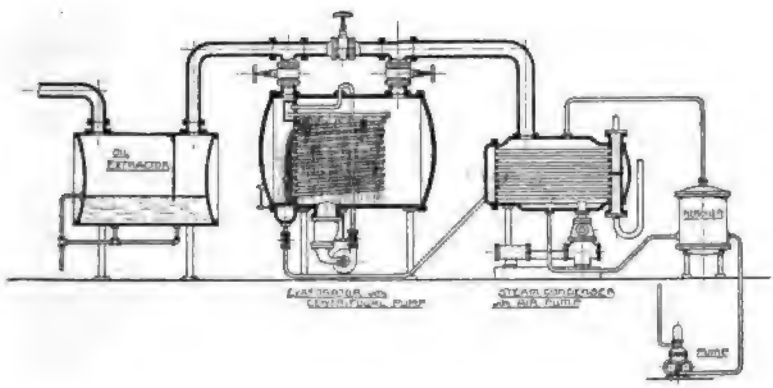
As has been mentioned, by means of an evaporator it is

possible to take full advantage of the economy of a high class compound condensing engine. This apparatus is similar to that referred to in Chapter XVI and shown in Figs. 60 and 61 as used for the evaporation of fresh water from sea water.

A view of such an apparatus with accessories is shown in Fig. 65.

The oil extractor represents the apparatus used to cleanse the exhaust steam so that the same may be utilized in the ice product. The exhaust steam is condensed in the steam space

FIG. 65.



THE "LILLIE" EVAPORATOR.

"Lillie" evaporator combined with oil extractor, steam condenser, air pump and reboiler.

of the evaporator, the water formed being delivered to the steam condenser.

The water vapor formed by evaporation in the vapor section is delivered to the steam condenser, where it is condensed. From the steam condenser the water is delivered to a reboiler, provided with a live steam heating coil, in which the air and foreign gases are driven off from the water. These gases are driven over to the vapor space of the condenser, from which they are removed by the air pump.

The vapor spaces of the evaporator, condenser and reboiler are all connected. The pressure in these spaces is maintained low by means of the air pump. On account of this low pres-

sure, or partial vacuum, the vaporization of water is effected at low temperature.

From the reboiler the water is delivered by means of a pump, the speed of which is regulated by a float in the reboiler, to the usual skimming tank, from which the water follows its usual course to the cold water storage tank.

CONDITIONS OF OPERATION.

The pressure in the steam space corresponds to the vacuum maintained for the condensation of the steam engine. This may be varied somewhat for different seasons, running from about 21″ in cold weather to 18″ or 16″ in summer, when the higher output is demanded of the evaporator. The conditions for operation in the latter case are approximately as follows:

CONDITIONS OF OPERATION IN EVAPORATOR.

	Degree of Vacuum.	Corresponding Temperature of Steam and Water.
Steam space	18″	169° F.
Vapor space	26″	126° F.
Condenser	26″	126° F.
Re-boiler	26″	126° F.

The temperature of the water delivered from the condenser to the re-boiler would depend upon the drop in temperature en route, which might amount to 5° or 6° F. This would represent the amount the temperature of the water would need to be raised in the re-boiler to produce ebullition.

RESULTS.

Values for results obtained for the conditions mentioned above are as follows :

RESULTS OBTAINED WITH LILLIE EVAPORATOR.

Water evaporated per lb. of steam	$\frac{7}{8}$ lb.
Steam required for 100 tons water :—	
Basis as per above	53.3 tons.
Allowing for losses	73 to 75 tons.
Ice production. Can system. Results obtainable :—	
Tons of ice per ton of coal	10 tons.
Increase in production in tons 10—6 =	4 tons.
Increase in production	40 %.
Practical results :—	
Increase in ice production	25 %.
Increase in cost of plant	15 % to 20 %.

The results given would seem to put the can system of ice production from distilled water about on an equivalent basis with the plate system.

AMMONIA COMPRESSORS.

It may be readily inferred that the ammonia compressor, the part in which the compression takes place, is the characteristic feature of the apparatus employed in the ammonia compression system. Compressors, however, are not all alike. There are a number of different styles of compressors as regards details of construction, and a few different plans of operation, so that it may be said that there are several different kinds of compression systems. The variety of compressors corresponds more or less to that for steam engines, with a few more added. For instance, there are vertical compressors and horizontal compressors, single acting and double acting. Even compound compressors have been used. Then as regards operation, there is wet compression and dry compression. Methods of cylinder cooling include use of water jacket; injection of oil; injection of liquid ammonia; or simply the cooling effect of unevaporated liquid ammonia drawn into the cylinder with the vapor in the suction stroke in the wet process.

Examples of different apparatus employing the various features mentioned, excepting compounding, are enlarged upon in Part II, following. As the apparatus described is in all cases such as is in successful practical operation, it is evi-

dently not possible to make a definite statement as to which one is the best. It may be well to consider some of the claims that are made for some of the different styles and a few special features.

VERTICAL COMPRESSORS.

With vertical compressors the wear of the cylinder, piston, piston-rod, and stuffing-box, is reduced to a minimum, and, furthermore, such wear is uniform on all sides. There is also

FIG. 66.

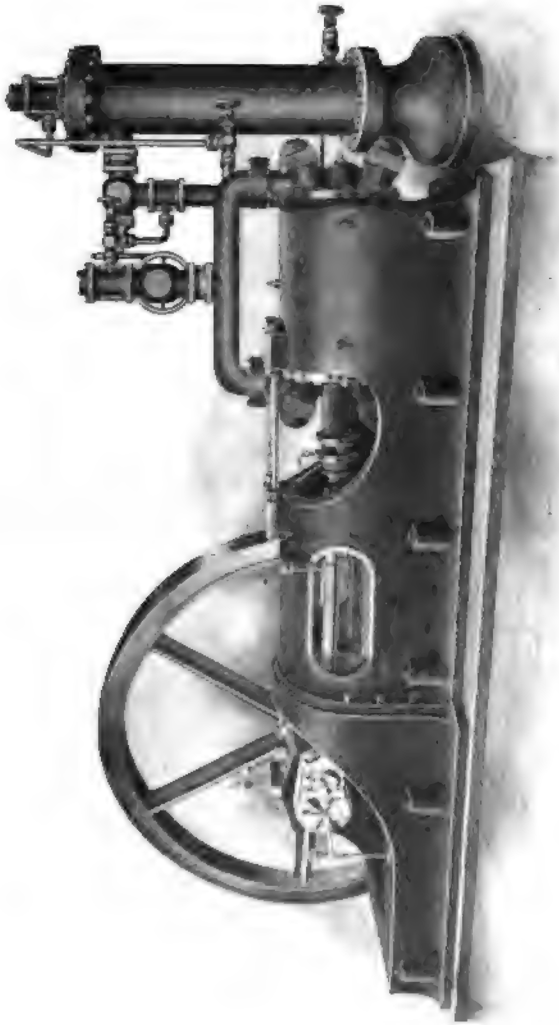
VERTICAL SINGLE-ACTING REFRIGERATING MACHINE
Newburgh Ice Machine and Engine Co.

economy in floor space. With a horizontal engine and a proper arrangement of cranks the period of maximum compression may be made to correspond to the period of maximum effect in the steam cylinder, certainly an ideal arrangement. A view of a pair of single-acting compressors is shown in Fig. 66.

HORIZONTAL COMPRESSORS.

In horizontal compressors the lines of strain are brought close to and parallel with the foundation, giving superior

FIG. 67.



85-TON FEATHERSTONE COMPRESSOR.

stability and rigidity to the structure. Another feature is the accessibility of all the parts. Machines of this type have been in continuous use for twenty years without re-boring of cylinders, showing that the feature of oval wear of cylinder and piston is not a very serious difficulty with horizontal machines. Horizontal machines are almost invariably double-acting. An illustration of a compressor of this type is shown in Fig. 67.

SINGLE-ACTING, VERTICAL.

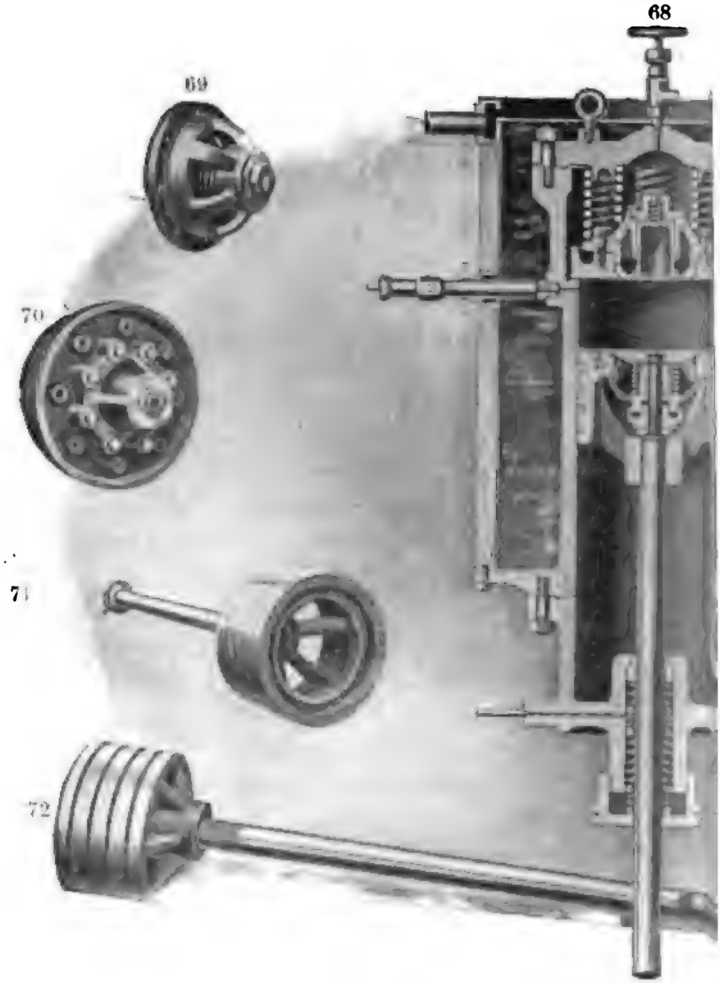
Practically all single-acting machines are of the vertical type. In this class of machines the clearance at the end of the stroke may be adjusted to a minimum. It is possible to use in this type a safety compressor head, covering the end of the cylinder. This is held in place ordinarily by a heavy spring, which, however, will give way in case a solid obstruction or a superfluous amount of liquid should happen to be admitted to the space between the cylinder-head and the piston. In other words, it is a large valve that can be forced open by the piston in case of emergency, and thus save expensive and serious damage to the apparatus and possible loss of ammonia.

With this type generally the ammonia vapor is admitted to the space in the lower portion of the cylinder, below the piston. This tends to keep this portion of the cylinder and piston cool, and being at comparatively low pressure, reduces the difficulty of the problem of packing the stuffing-box for the piston-rod.

A good plan followed in many cases is to have the suction-valve in the piston. It can be made of ample size, and especially reliable and effective in operation.

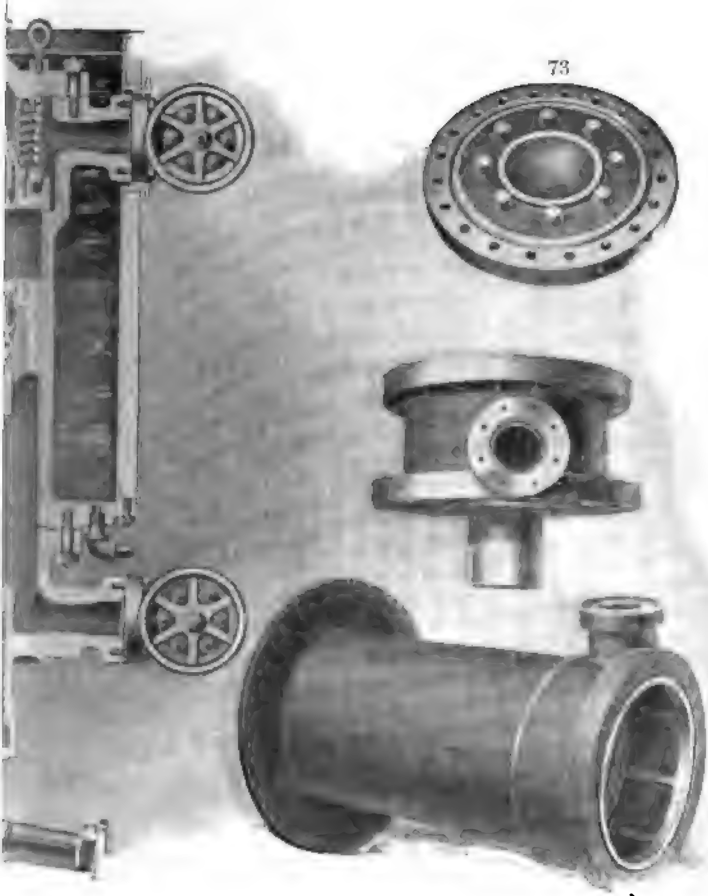
Machines of this type are almost invariably equipped with a water jacket for cooling the cylinder.

The compressor cylinder shown with details in Figs. 68 to 75 inclusive, contains the various features mentioned, namely, vertical stroke, single action, safety-head, admission of suction vapor below piston, suction valve in piston, and also water-jacket for cooling the cylinder.



FIGS. 68 TO 75 INCLUSIVE.—

Fig. 68—Sectional View. 69—Suction Valve. 70—Discharge Valve. 71 and 72—


73

74

75

-AMMONIA COMPRESSOR AND DETAILS.

-Ammonia Pistons. 73—Compressor Cover. 74—Compressor Base. 75—Compressor Cylinder.

(Opposite page 152.)

Machines of the vertical single-acting type of the larger sizes are generally erected in pairs. This type of construction has been employed for some of the largest machines that have ever been built. In other words, this type of machine seems to hold the record for size.

Machines of this type, complete with horizontal steam engines, are shown in Fig. 66 and in the Frontispiece.

DOUBLE-ACTING COMPRESSOR.

Double-acting machines economize in floor space for the same power, and also in duplication of parts, including cylinder and piston, and also save in the friction losses. The saving corresponds to that of a double-acting steam engine over a single-acting engine. As has been stated, horizontal machines are generally made double-acting. Vertical double-acting machines are also used, including large capacity machines. Views of double-acting machines are shown in Fig. 67, and in connection with the diagrammatic view of a refrigerating plant, Fig. 3.

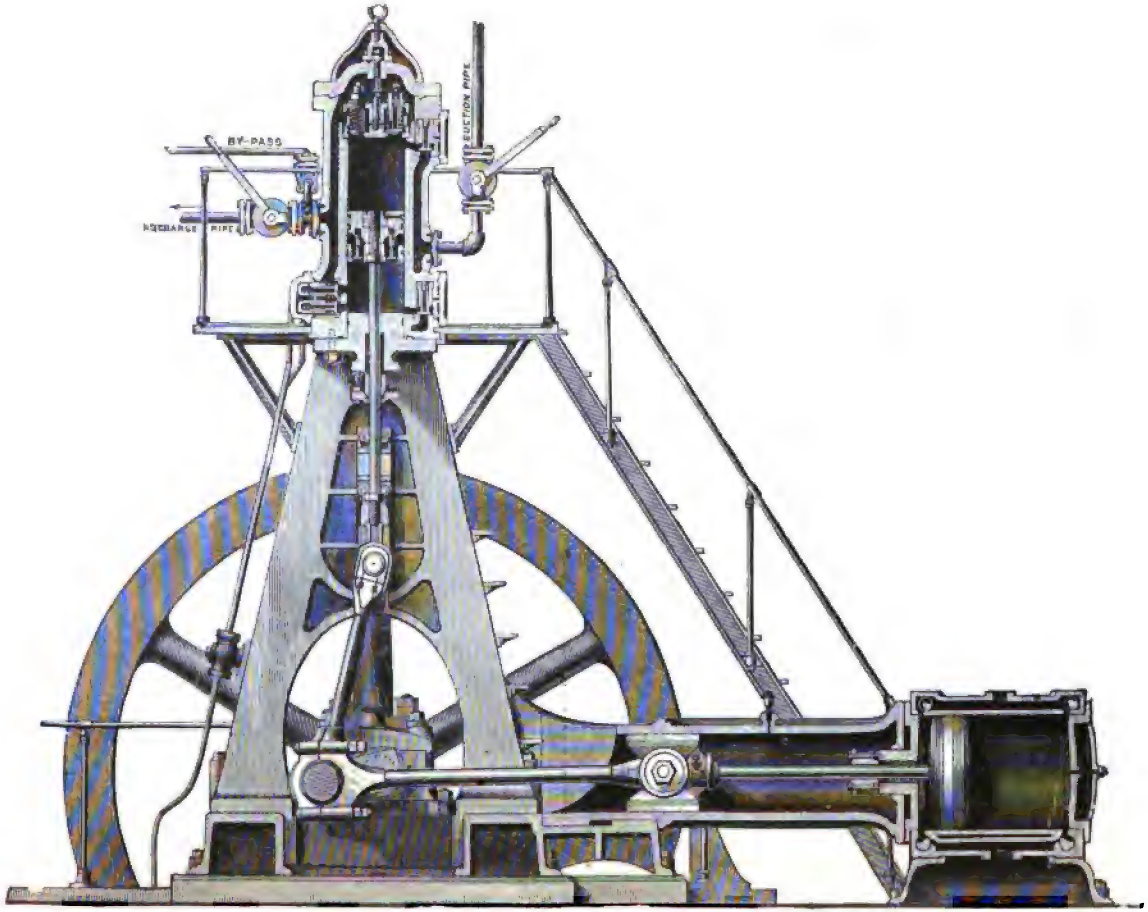
OIL INJECTION.

The idea of oil injection is for lubrication and for filling clearance spaces to the exclusion of ammonia vapor. The former idea is well realized, the latter, however, only partially. The clearance spaces are filled thoroughly enough, but not to the exclusion of ammonia, as under the extreme pressure used a considerable quantity of ammonia is absorbed by the oil remaining in the cylinder. This ammonia re-expands during the suction stroke, occupying space to the exclusion of a corresponding amount of fresh vapor from the expansion coils. In Fig. 76 is shown an illustration of a vertical double-acting machine of this type.

OIL SEPARATING APPARATUS.

Operation with oil injection involves the use of a somewhat complex system of apparatus for the removal of the oil from the ammonia. This consists of a fore-cooler or oil cooler,

Fig. 76.



SECTIONAL VIEW OF VERTICAL REFRIGERATING MACHINE OPERATING WITH OIL INJECTION.
De La Vergne Machine Co.

built after the plan of a condenser, in which the greater part of the oil is removed before the ammonia enters the condenser; a pressure tank in which the oil is deposited from the fore-cooler; and a separating tank, in which any remaining oil is trapped from the liquid ammonia after condensation.

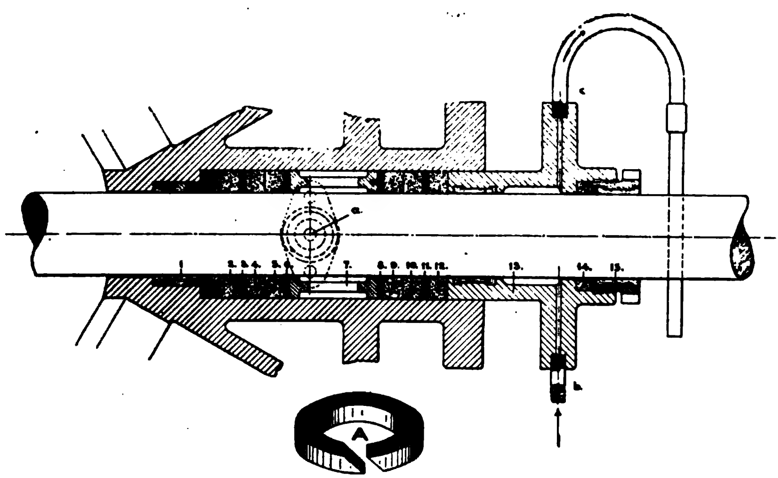
These features are given further attention in Part II, Chapter II, describing the De La Vergne apparatus.

For ordinary compressor systems the oil separator consists of a simple oil trap built after the plan of a steam separator, with baffle plates for catching the entrained oil.

STUFFING-BOX.

There is no questioning the importance of the stuffing-box of the compressor. A leaky stuffing-box means loss of am-

FIG. 78.



monia. Considerable attention and ingenuity have been expended in developing this feature, with the result that an efficient and reliable construction has been produced. A typical method is shown in the illustration, Fig. 78. An explanation of the construction and method of packing is given herewith.

Referring to the numbers used in this figure, numbers 2, 4,

5, 9, 10, 12, and 14, indicate packing rings made from the composition of rubber. These should never be used solid, but should be cut as shown in sketch "A." Numbers 3, 6, 8, and 11 represent metal rings, made from pure tin. They are intended to keep the rubber rings in proper condition. These rings should always be one-sixteenth of an inch larger than the rod and should never be cut in two, as otherwise they are apt to score the rod. If it is necessary to put in new metal rings, disconnect the piston rod from the crosshead and slip the rings over the end of the rod. Under no circumstances pack the compressor without the metal rings.

Number 7 designates the lantern which forms an oil storage reservoir in the middle of the stuffing-box. The oil supply is taken in at the point marked "a" through a pipe connection from the oil trap. This passage being always open, the oil is forced into the stuffing-box by the high pressure gas in the oil trap, keeping this stuffing-box and lantern always full and instantly replacing what little oil is carried into the cylinder on the rod. Number 13 is the stuffing-box gland which is supplied with oil through the inlet "b" from a small oil pump operated from the main shaft. This oil overflows at "c" and is led back to the oil pan to be recirculated.

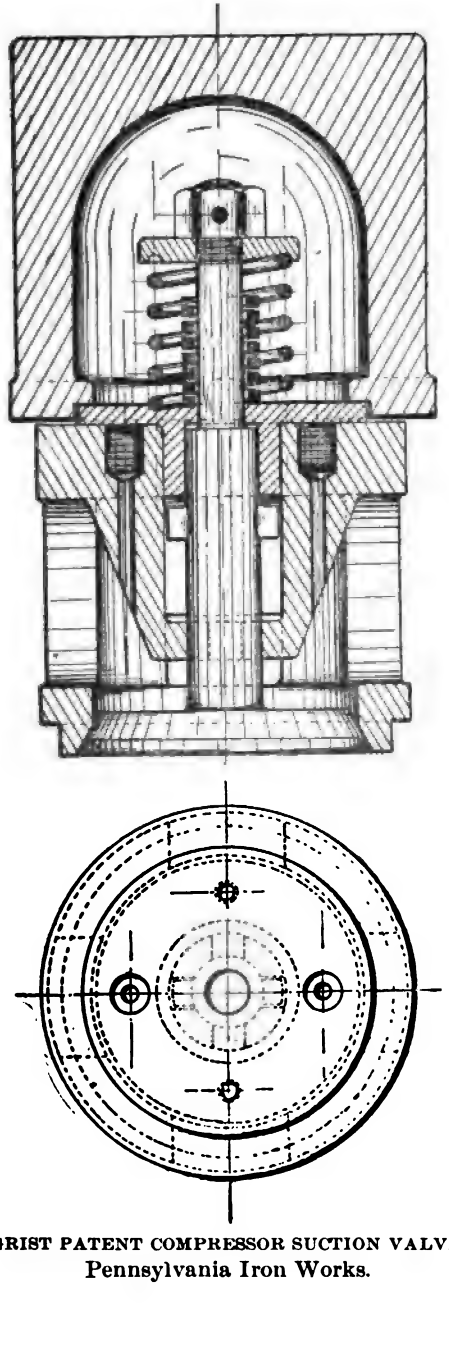
Number 15 is the oil gland which should be kept just tight enough to keep the oil in the stuffing-box gland. The points of contact with the rod are numbers 1, 13, and 15, and they must fit the rod properly. If it becomes scored and is turned down, these parts must be rebabbitted. Great care should be used not to tighten the stuffing gland 13 more than is necessary to prevent the ammonia from leaking.

In the case of single-acting machines the stuffing-box is subjected only to the low pressure of the suction system. Accordingly, the construction of the stuffing-box for these machines is considerably less elaborate, as will be noted from an inspection of Fig. 68.

COMPRESSOR VALVES.

The suction and discharge valves are invariably spring

FIG. 79.



GRIST PATENT COMPRESSOR SUCTION VALVE.
Pennsylvania Iron Works.

actuated. Valves at the end of the cylinder, remote from the stuffing-box, are generally located in the cylinder-head, as shown in Fig. 68 and Fig. 76. Valves at the stuffing-box end, in double-acting machines, may be located in the cylinder-head or at one side, as shown in Fig. 76. Fig. 68 shows a suction valve in the piston. Valves are generally assembled complete, as a unit, in a cage, so that they may be readily removed and replaced, as shown in Fig. 69, Fig. 70, and Fig. 79.

CHAPTER XIX.

EFFECT OF BACK PRESSURE AND SUPERHEATING ON CYLINDER CAPACITY.

A compressor cylinder of definite dimensions and operating under definite conditions, would have a definite volume capacity. The capacity by weight would, however, depend upon the density of the medium. The density of the medium would depend upon the pressure and upon the physical condition of the medium. The physical condition of the medium with a given pressure would depend upon the temperature.

Below a certain temperature the medium would be in what is known as the saturated condition. In this condition the medium is classed as a vapor. A vapor is either in contact with some of the liquid from which it is formed or it is just at the point of complete evaporation. The temperature of the vapor would be the same as that of its mother liquid. There is a definite relation between temperature, pressure, and volume for a vapor, values for these being published in tables for different substances, including ammonia.

Above this certain temperature the medium is in what is known as a superheated condition. In this condition the medium is called a gas. The relation between temperature, pressure, and volume of a gas, is expressed by an exponential function as follows:

$$\frac{T_1}{T_2} = \left(\frac{P_1}{P_2}\right)^{\frac{K-1}{K}} = \left(\frac{V_2}{V_1}\right)^{K-1}$$

in which T, P, and V represent respectively temperature, pressure and volume, and $K = 1.30$ for ammonia.

An inspection of the ammonia tables will show that for a vapor the capacity would depend upon the pressure, and the

formula given shows that for a gas with a definite pressure the capacity would depend upon the temperature.

CAPACITY AND BACK PRESSURE.

It is generally assumed that the capacity of an ammonia compressor varies directly as the back pressure. That this is nearly correct is shown from the abstract from the ammonia table given herewith.

DENSITY OF AMMONIA VAPOR AT SUCTION PRESSURE.

Temperature. F.	Absolute pressure lbs. per sq. in.	Weight of vapor per cubic foot lbs.
—40°	10.69	.0410
—15°	20.99	.0779
0°	30.37	.1107
15°	42.94	.1541
30°	59.42	.2099

While the actual work of compression bears a somewhat close relation to the density of the vapor, the friction losses do not vary appreciably for different conditions. Accordingly, with a reduction in capacity due to reduction in suction pressure, there is no corresponding diminution in the gross work of compression and in the expenses of operation.

The conditions are further complicated by the increase in the range of working temperatures involved in a reduction of temperature corresponding to the reduction in pressure.

The relation between capacity, work, and cost of operation, are very plainly set forth by a set of three curves in the chart shown in Fig. 80, developed by the De La Vergne Machine Co. One curve shows the diminution in capacity corresponding to the diminution in back pressure, the other two curves showing the corresponding changes in work required and cost of fuel.

A few figures taken from these curves are here given.

With a capacity of 10 tons at a return or back pressure of 28 pounds per square inch, the capacity at a return pressure of 6 pounds per square inch is reduced to 5 tons only. The ratio showing the corresponding change in the cost of fuel is 14.5 to 25. In other words, the cost per ton of fuel is nearly doubled while the capacity is halved.

FIG. 80.

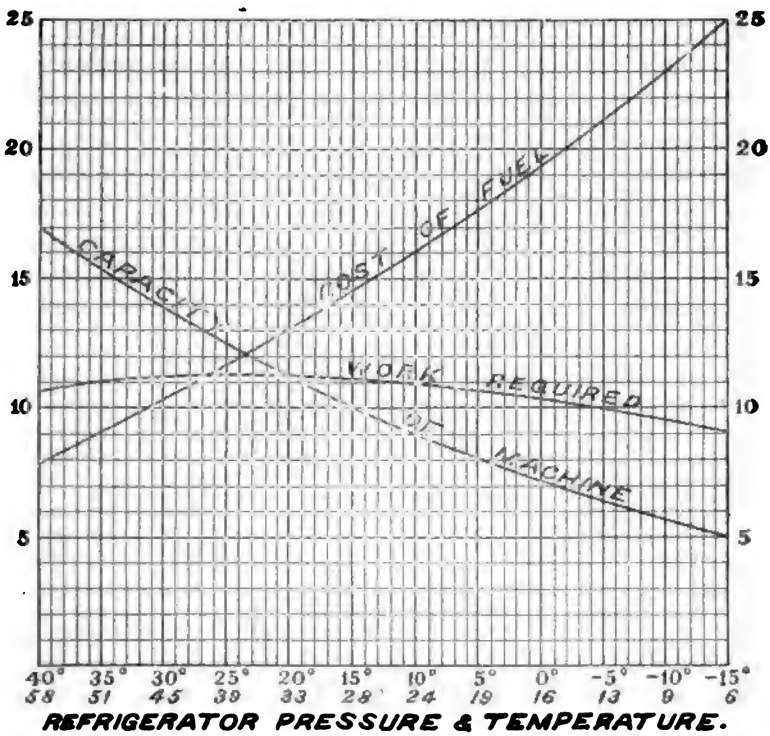


CHART SHOWING RELATION BETWEEN PRESSURE, WORK, AND COST OF FUEL.

While these figures might be altered under different situations, they undoubtedly indicate very closely a state of facts that cannot be set aside.

The bearing of these facts upon the indirect or brine system of refrigeration is evident. As the brine pipes should be

essentially at the same temperature as the direct-expansion pipes which they replace, the ammonia in the direct-expansion pipes in the brine tank for the purpose of reducing the temperatures of the brine must be at a lower temperature than that of the brine. This means, of course, that the ammonia in the indirect system must be brought to a lower temperature than in the direct system. This reduction in temperature means a reduction in back pressure.

If the difference in temperatures be 10°, that is, the temperature in the refrigerating coils be 5° instead of 15°, then the capacity of the machine is reduced in the ratio of 10 to 8, or 20 per cent., and the cost of fuel is increased in the ratio of from 14.5 to 17.5, or 20 per cent.

Nevertheless, in practical operations, the range in working temperatures, as well as the choice of refrigerating medium and other features, are not determined strictly from a thermodynamic standpoint. At the same time the theoretical developments serve as a guide as to the path to follow in case there are no restrictions to the contrary.

CONDITION OF SUPERHEAT.

For a given pressure the temperature for a gas will be higher than for the vapor, and with a rise in temperature there will be an increase in volume for either gas or vapor.

It follows from this that the effect of superheating on the refrigerating capacity of a compressor corresponds in a general way to that of a drop in suction pressure. In both cases the result is a reduction in capacity due to a reduction in the density of the medium, a vapor in one case and a gas in the other.

It is evident from what has been stated above that the temperature of the medium at the beginning of compression, and consequently the volume of the same and the capacity of the compressor depend upon the condition of the medium as to superheat. Accordingly, in case the medium in the refrigerating coils is evaporated to dryness there would be superheating on the way to the compressor, with a consequent drop

in the refrigerating capacity of the compressor. This is a condition that may be readily determined and as well controlled in a given case.

There is, however, an unaccountable loss in refrigerating capacity in practice over the theoretical value, generally accepted to be about 25 per cent., which is generally attributed to the superheating effect of the hot walls of the cylinder.

It would seem from this that an efficient cylinder cooling arrangement would have the double effect of keeping down the maximum temperature of compression, and assisting materially in augmenting the effective refrigerating capacity of the compressor.

CHAPTER XX.

WET AND DRY COMPRESSION.

CONSIDERABLE energy has been expended in discussion of the relative merits of wet and dry compression, and the end is not yet. The arguments presented are generally interesting and instructive, though not conclusive, because there is generally something left out.

The fact remains that there are advocates of wet compression who practice what they preach, even to the extent of doing away with other methods of cylinder cooling entirely. They have been doing so for years, evidently to the satisfaction of all concerned.

Then again it is not certain that those who advocate dry compression adhere to this method exclusively. The usual water jacket may be in use, and in addition some unevaporated vapor may be drawn into the cylinder to assist in the cooling, so that the saturated condition prevails for at least a part of the period of compression.

The term wet compression is applied, strictly speaking, to compression with the medium in the saturated or humid condition throughout the entire compression period. In other words, it applies to the compression of a vapor.

Dry compression, on the contrary, would apply to the compression of a gas.

It is evident that between these two extremes there is no limit to the number of degrees of humidity that may prevail.

There is no doubt but what, with a given pressure, the degree of humidity would have some bearing on the temperature and work of compression.

When a gas or vapor is compressed, the heat-equivalent of the mechanical work of compression tends to raise its temper-

ature and pressure. Consequently its pressure is more rapidly raised than would be the case if it could be maintained at constant temperature.

In the compression of a dry gas, unless heat is withdrawn by means of a water jacket, or other cooling device, the adiabatic curve will be traced on the indicator diagram. This is the curve which represents the compression or expansion of a gas without loss or gain of heat.

If it were possible (as it is not) to maintain the gas at the same temperature throughout its compression, the isothermal curve would be traced by the indicator pencil. This is the curve representing the expansion or compression of a gas at constant temperature.

The area between these curves on a diagram represents the heat equivalent of the mechanical work done in compressing the gas. Therefore, the more nearly the actual compression curve follows the isothermal, the more economical will be the operation of the machine.

In the humid-gas machines, the ammonia is carried back to the compressor in a saturated condition and the heat of compression is taken care of by the unexpanded ammonia, which, in the form of fog or vapor, entered the compressor on the suction stroke.

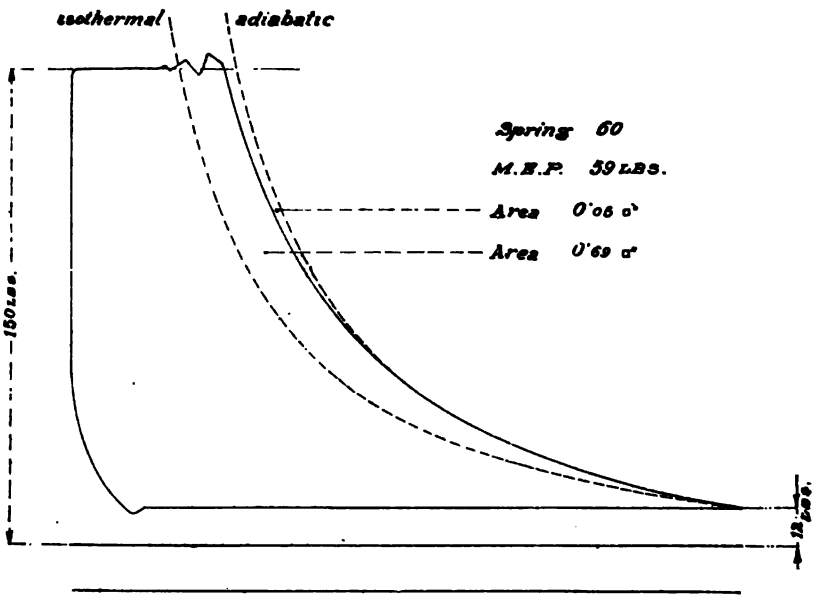
The diagrams, Figs. 81 and 82, are intended to show graphically the comparative efficiency of this method of cylinder cooling and the water-jacket system employed in dry-gas machines.

The initial volume and pressure, and the terminal pressure are the same in each case. In the compression of the dry gas, the compression curve necessarily follows for a considerable distance the adiabatic line. This for the reason that the gas coming into the cylinder from the expansion coils is at a temperature of —5° Fahr., and no heat can be transmitted from it to the cooling water in the water jacket until the temperature of the gas has been raised above that of the water, which is probably 60° to 70° Fahr. The compression curve then leaves the adiabatic and during the last part of the stroke,

before the discharge valve opens, approaches the isothermal line.

In the compression of saturated vapor, the unexpanded ammonia begins immediately to absorb the heat of compression, the compression curve at once leaves the adiabatic and approaches the isothermal line, making a diagram that is

FIG. 81.



Dry Gas

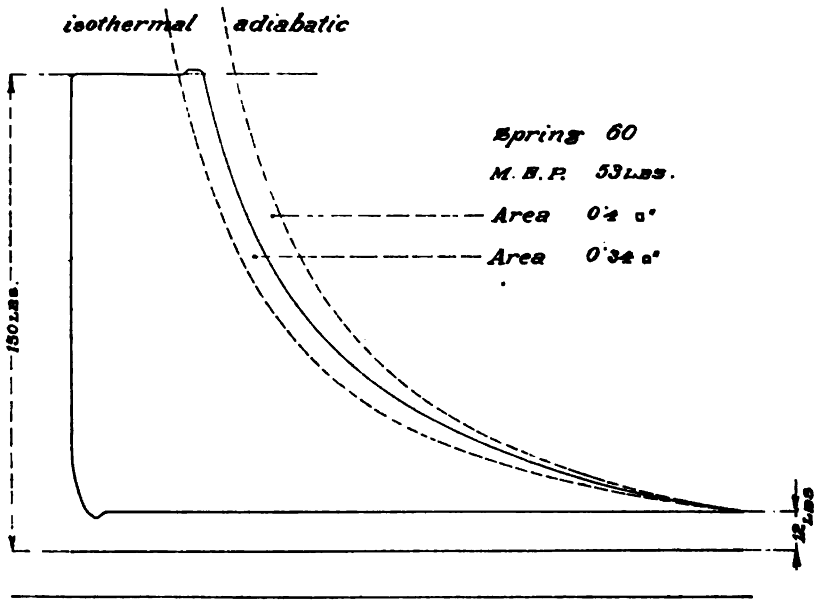
much smaller in area and which, therefore, represents work requiring less power.

The efficiency ratio of any cylinder-cooling device is found by dividing the area between the actual compression curve and the adiabatic curve, by the total area between the adiabatic and isothermal curves.

In the diagram referred to, this efficiency is 54 per cent. for the humid gas compressor and 6¾ per cent. for the dry-gas machine.

Assuming that the diagrams shown are from eighteen by thirty inch double-acting compressors, running at fifty revolutions per minute, the effective horse-power required for the

FIG. 82.



Saturated Vapor

compression of the saturated vapor would be 102.1 horse-power, as against 113.7 horse-power for the dry-gas machine, a gain of 10.2 per cent. in favor of the humid system of operation.

CHAPTER XXI.

AMMONIA CYLINDER CARDS.

As an illustration of a practical and thorough method of examining and studying indicator diagrams obtained from cylinders of ammonia compressors, the description given below may be accepted as an exemplary type,* although in this particular case the card was taken from a double-acting vertical compressor, operating with oil injection.

In examining this card, hold it in an upright position and remember that the action is directly opposite to that of a steam card.

"O" is the beginning of the compression or up stroke of the piston.

"G" the compression line as the piston ascends in the cylinder.

"A" is the point at which the discharge valve was opened.

"Y" gives the point at which to establish the amount of compression pressure or the pressure held in the discharge chamber over the valves. In this card it is 175 pounds per square inch.

"A" to "Z" is the unbalanced pressure per square inch. In this card it is eight pounds. This is required to lift the valve from its seat caused by the area of the top of the valve being larger than the area on the piston side.

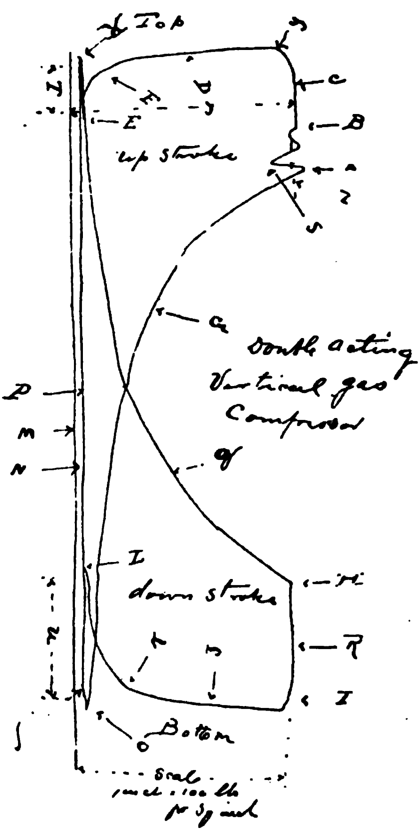
"S" shows the reaction of the indicator spring caused by the sudden release of the discharge valves. In fact the condition of the card from "A" to "B" is caused by the jumping of the indicator piston spring.

"C" is the line of discharge showing what pressure is maintained in the discharge chamber when the valves are open.

* Francis H. Boyer, A. S. M. E.

"C" to "Y" shows the gradual reducing of the pressure, and is caused by the reducing of the speed of the piston in passing the end of the stroke and lessening of the speed at which the gas is being expelled from the compressor.

FIG. 83.



AMMONIA CYLINDER CARD.

"Y." At this point the stroke is complete and the piston starts to recede or to take in the charge from the suction side.

"E." The piston has traveled from "Y" to "T," equaling $7\frac{1}{2}$ per cent. of entire length of the stroke, before the pressure above the piston is reduced to the pressure of the incoming gas. This is called clearance space, or the space between the

top of the piston and the cylinder head, which includes openings for discharge valves, etc. While this space is undoubtedly filled with oil, this oil is forced full of gas by its being brought under the intense pressure of 175 lbs. to the square inch.

"M" is the atmospheric line.

"P" is the return or suction pressure at which the gas is admitted to the cylinders, in this case 8 lbs. per square inch above the atmosphere.

"O" is the completion of the suction stroke. The raising of the pressure on the down stroke from "V" to "O" indicates that the valve opening into the cylinder is not of sufficient size to admit of the free entering of the gas.

This condition is shown on the discharge also from "C" to "Y." The pressure in the discharge chamber is without doubt about 164 lbs. per square inch, as shown from the atmospheric line to a point at "Y." It is more than probable that the compressor was run above its normal speed, as there is a marked uniformity in these two defects.

On the down stroke the conditions of the discharge card are the same, with few exceptions, the most prominent of which is the large space which the piston must travel before the suction valve opens, or at the point "L," traveling from "J," or the distance "U," which equals 21 per cent. of the cylinder area of the stroke.

We have the following conditions:

7½ per cent. loss on top stroke.

21 per cent. loss on bottom stroke.

29½ per cent. loss on each revolution by gas and oil remaining in the compressors.

The cause of nearly three times as much loss on the down stroke of the compressor is the increased amount of clearance on this stroke which is necessary to accommodate the wear of the journal and rod brasses, which allows the piston to come lower down in the cylinder and decreases the clearance on the bottom in proportion to the increase of clearance on the top.

The absence on the down stroke of the jumping of the indi-

cator at the opening of the discharge valve at "H," as shown on the up card from "A" to "B," is due to the fact that the bottom of the cylinder is filled with oil and the indicator pipe is also filled and the thrusts from other valves' opening is taken up on the elasticity of the oil in indicator tube. The clearance of the piston on the top stroke is about $\frac{3}{64}$ of an inch and the bottom $\frac{3}{8}$ of an inch.

CHAPTER XXII.

ENTROPY-TEMPERATURE DIAGRAM.

Amongst the much good and more not so good material available that must be rejected per force of circumstances in the preparation of a volume of this kind is included much of interest and merit along the line of the thermodynamic features.

In the present instance we are going to admit that space will not permit doing justice to this important feature. We will accordingly leave considerable to the various treatises on thermodynamics, confining ourselves to such occasional references to the principles as are interspersed in the various problems presented in the midst of the text and to the consideration of the special topic given at the head of the chapter.

The general utility of the entropy-temperature diagram for representing thermodynamic conditions has received some recognition in connection with problems on refrigeration. It is the intention to present herewith an illustration of the application of this diagram to the compression system generally, with a problem worked out as applied to the ammonia compression system. The method followed corresponds to that shown in Reeve's "Thermodynamics."

DEFINITION OF ENTROPY.

A number of different definitions have been given by different authorities for entropy, or heat-weight, as it is sometimes called, none of which give a very good conception of the term.

Reeve gives it as follows: "Entropy is that quality of a body which increases when heat is added to the body, which decreases only when heat is abstracted, and, consequently, remains constant only when heat is neither added or abstracted."

FUNDAMENTAL EQUATION AND NUMERICAL VALUE.

The fundamental equation for entropy is a differential equation as follows:

$$dN = \frac{dQ}{T}, \qquad (1)$$

in which N = entropy, Q = quantity of heat contained in the body, and T = the absolute temperature.

As it is not possible to determine exactly the value for Q, the quantity of heat contained in a body, it is not possible to obtain an absolutely correct value for entropy. It is, however, possible to determine values suitable for use in calculations from an arbitrary basis. In the case of calculations on steam, the calculations on quantity of heat and entropy are generally determined with reference to the freezing-point of water, 32° F. or 0° C. In the case of ammonia, as involved in problems on refrigeration, the same point is sometimes taken as a basis, though more generally the zero of the Fahrenheit scale seems to be used. This is the point that will be used as a basis in the problems that are to be worked out herewith. In other words, at temperature $t_0 = 0°$ F., or $T_0 = 460.7°$ F., Q = 0 and N = 0.

For other temperatures:

$$dN = \frac{dQ}{T}.$$

ENTROPY-TEMPERATURE DIAGRAM.

The entropy-temperature diagram is generally plotted with entropy (= N) as abscissae, and with temperature (absolute temperature = T) as ordinates. A series of such curves for entropy and temperature is shown in Figure 84.

ENTROPY-TEMPERATURE CURVES FOR AMMONIA.

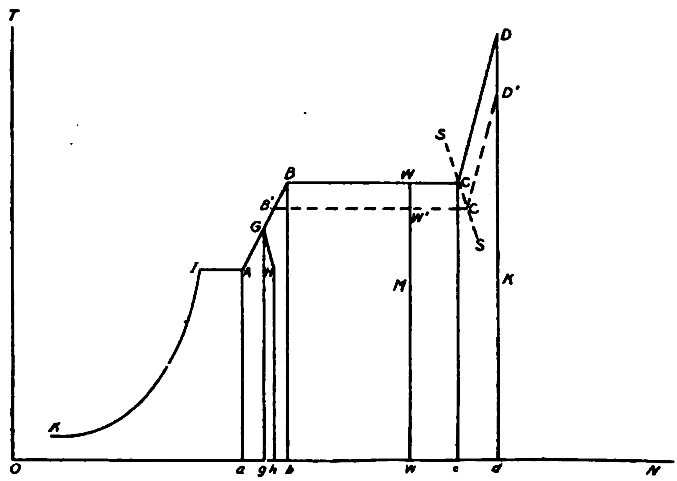
In Figure 84 are shown in a general way the curves that apply to the conditions prevailing in the case of ammonia used in the compression system, which also includes curves

representing conditions at lower temperatures than prevail under operating conditions.

The explanation of these curves will now be considered.

Curve A B represents the liquid condition. In this case the change in heat within the body, corresponding with change in temperature, depends upon the range in temperature and the specific heat of the liquid. This curve is known

FIG. 84.



as the curve of heating and cooling, or the isomorphic curve. The formula for this curve is as follows:

$$N - N_1 = S \log_e \frac{T}{T_1}, \qquad (2)$$

in which N = entropy at absolute temp. T, N_1 = entropy at absolute temp. T_1, and S = specific heat of the liquid.

Curve A I represents the condition of change of state, from liquid to solid, in which latent heat is given up at constant temperature. This curve is known as the curve of constant temperature, or isothermal, and is represented by the formula:

$$N - N_1 = \frac{Q}{T} \qquad (3)$$

Curve I K represents the solid condition of the medium. As in the case of curve A B, the condition in regard to heat depends upon the value for specific heat, in this case of the solid, and the same formula applies so long as the specific heat remains constant. As the value for specific heat is not known for the lower temperatures, the location of this curve is indeterminate.

Curves A I and I K are beyond the range of operations in the ordinary refrigerating processes. The curves shown to the right of A in Figure 84 are within the range of operations, and are of immediate concern.

Curve A B has already been mentioned, the formula for the same being

$$N - N_1 = S \log_e \frac{T}{T_1}.$$

Curve B C represents the condition of absorption of latent heat of vaporization. As this takes place at constant temperatures, with constant pressure, the curve is another isothermal, represented by the formula—

$$N - N_1 = \frac{Q}{T}. \qquad (3)$$

Curve C D represents the condition of superheat, in which condition the ammonia is considered to have reached the state of a gas, as distinguished from a vapor, and accordingly the thermodynamic condition is governed by the laws for perfect gases.

As such changes in the thermodynamic condition do not involve a change in the physical state, the formula for the curve representing the condition of C D is the isomorphic curve as for A B, differing from the same numerically in that the value used for specific heat is that for the gas at constant pressure:

$$N - N_1 = S \log_e \frac{T}{T_1}.$$

Curve S S_1 is made up of a series of points similar to C, representing the condition of complete vaporization of liquid at which superheat begins.

As the point C is considered to have been reached along the path A B C, the thermodynamic condition at C is reached through the laws applying to the elements of this path, A B and B C. In a similar way the condition corresponding to any other point along S S_1 may be determined.

Curve G H represents the curve of constant heat or wire drawing, in which the medium drops in temperature, or the heat falls without performing mechanical work. This curve is represented algebraically by the formula—

$$N - N_1 = S \left(\frac{T_1 - T}{T} - \log_e \frac{T_1}{T} \right). \quad (4)$$

Curve M W represents the condition of adiabatic compression or expansion for the saturated condition of the medium, or condition of vapor as distinguished from a gas. The curve for this condition is a vertical line, represented by the formula—

$$N = \text{a constant.} \quad (5)$$

Curve D K also represents a condition of adiabatic change, compression or expansion, applying, however, to the condition of superheat or a gas. This curve is likewise represented by the same formula—

$$N = \text{a constant.} \quad (5)$$

HEAT VALUES.

The area underneath any of the curves mentioned in the previous discussion represents the heat value for the heat entering or leaving the medium. These heat values are determined as follows:

For the general case we have the following formula:

$$dQ = TdN. \quad (I)$$

For curve A B, representing the heat of the liquid, we have

$$Q = l - l_1 = S(T - T_1), \qquad \text{(II)}$$

in which S = specific heat of the liquid. Values for l and l_1 are obtained from ammonia tables.

Curve B C represents the condition of vaporization at constant temperature. The heat for total vaporization at C is represented by L, the value for which is obtained from the tables. Any point between B and C represents condition of incomplete vaporization, the value for which in per cent. is called the degree of wetness. If for point W we have K = degree of wetness in per cent., and $d = 1 - \frac{K}{100} = \frac{100 - K}{100}$, then we have the formula for B C.

$$Q = L \times d. \qquad \text{(III)}$$

It will be noted that

$$d = \frac{BW}{BC}.$$

Curve C D represents condition of heating a gas, or superheat, at constant pressure. The formulæ that apply to this case are similar to those for curve A B, with the value for specific heat of ammonia gas at constant pressure used instead of specific heat of the liquid.

Accordingly, formula (II) should be used for determining the heat value.

Curve S S, representing the locus of the points for the end of vaporization and the beginning of superheat, is determined from a combination of formulæ (II) and (III), because the total heat at this point is made up of the heat of the liquid and heat of vaporization, or $H = l + L$.

Curve G H represents the condition of constant heat or wire drawing. Accordingly we have $H_H = H_G = l_G$. The heat underneath G H is represented by the equation—

$$Q = S(T - T_1) - S\ T \log_e \frac{T}{T_1} \qquad \text{(IV)}$$

in which S = specific heat of liquid.

For the adiabatics W M and D K, being vertical lines, and corresponding also to the definition, we have—

$$Q = O. \qquad \text{(V)}$$

For change along the adiabatic W M we need to determine the value for heat of vaporization for the new level, as for instance B′ W′.

We have the following:

$$\begin{aligned}
N_W &= N_{W1} \\
N_W &= N_{ITW} + N_{LTW} \times d \\
&= N_{ITW1} + N_{LW1} \\
N_{W1} &= N_{ITW1} + N_{LW1} \\
N_{LW1} &= N_{W1} - N_{ITW1} \\
&= N_W - N_{ITW1} \\
L_{W1} &= N_{LW1} \times T_{W1} \\
&= (N_W - N_{ITW1})T_{W1} \\
Q_{B1W1} &= L_{W1} \doteq (N_W - N_{ITW1})T_{W1}
\end{aligned}$$

For change along the adiabatic D K we use these formulæ:

$$\begin{aligned}
Q_{C1D1} &= S(T_{D1} - T_{C1}) \\
N_D &= N_{D1} \\
N_{D1} - N_{C1} &= S \log_e \frac{T_{D1}}{T_{C1}}
\end{aligned}$$

S = specific heat of gas at constant pressure.

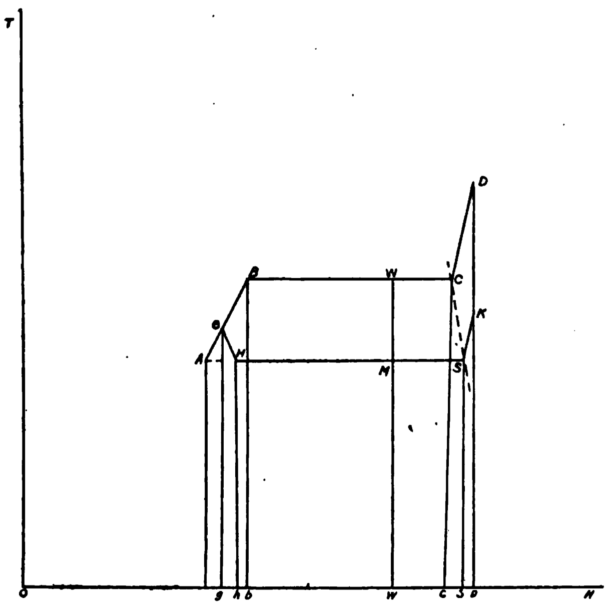
DIAGRAM FOR CYCLE OF OPERATIONS.

Each complete cycle of operations may be represented by a closed diagram. Variations in the conditions of operation would call for a change of shape and dimensions of the diagram, especially in case the diagram should happen to be drawn to scale. As a general rule the diagram is simply drawn up to illustrate in a general way the character of the

enclosing lines, the feature of exactness and accuracy being left to the mathematical part of the problem. In this way the diagram in Figure 85 is drawn up to represent a possible set of conditions, and one that is in common use in practice. This diagram is the figure G H S K D C B.

The characteristics of the lines enclosing this diagram have all been developed above. In fact, most of the lines will be

FIG. 85.



ENTROPY-TEMPERATURE DIAGRAM FOR COMPLETE CYCLE.

recognized from Figure 84 by the lettering which is made to correspond in Figure 85. This applies for all from H through G, B and C to D. The remaining curves are described as follows:

Curve H S is a curve of vaporization, similar to B C.

Curve S K is a curve of superheating at constant pressure, similar to C D.

Curve K D is an adiabatic, a straight plumb line. This, of course, represents the condition of change in temperature

without heat being added to or taken from the body. Although this is an ideal condition, not to be attained, it is nevertheless proper to use this as a basis for the thermodynamic consideration of the subject.

DESCRIPTION OF A CYCLE.

It will now be in order to follow around the diagram for the cycle of operations in the order in which they occur. In doing this it will be convenient to begin with the refrigerant in the liquid condition. This liquid might be taken from the condenser at the temperature of condensation, corresponding to the pressure in the condenser, or it might be taken from the liquid receiver at a somewhat lower temperature. In case of liquid fore-cooling the temperature might be considerably lower than that in the condenser. We will assume the beginning of operations to be at the expansion valve, with liquid taken from the receiver or fore-cooler at a temperature lower than that in the condenser. This condition corresponds to the point G. Through the expansion valve there is wire drawing down to the temperature and pressure of the refrigerator along G H.

Vaporization in the refrigerator or expansion coils follows along H S.

Superheating occurs in the piping from the refrigerator to the interior of the compressor along S K.

Compression occurs, assumed in this case to be without loss or gain of heat through the walls and piston, that is adiabatic, along K D, until the pressure reached corresponds to that in the condenser.

Then follows the removal of the heat of superheat, either in a fore-cooler or the condenser, along D C.

Condensation occurs in the condenser at constant temperature along C B. From the condenser the liquid passes to the liquid receiver or fore-cooler, in which there is a drop in temperature along B G.

This brings the refrigerant back to the initial point taken for the cycle, ready to pass through a repetition of the same.

COEFFICIENT OF PERFORMANCE.

The efficiency of performance may be considered from a thermodynamic standpoint as the relation between the heat taken in along the lower level, or Q_2, and that delivered at the higher level, or Q_1, which latter includes the work done on the refrigerant by the compressor, or Qw; or it may be considered from a practical standpoint as the relation between the useful refrigerating effect, Qu, and the work done, or Qw. This latter, which is the feature really wanted, is known as the coefficient of efficiency or performance. This is expressed by the formula

$$C_e = \frac{Q_u}{Q_w}.$$

The diagrammatic representation of these various heat values is as follows:

Q_2 = the heat entering on the low temperature, low pressure side, from G to K, represented by the area below G H S K or g G H S K d.

Q_1 = the heat rejected on the high temperature, high pressure side, from G to D, represented by the area below G B C D or g G B C D d.

Q_w = the heat equivalent of the work done by the compressor represented by the area G H S K D C B or $= Q_1 - Q_2$.

Q_u = the heat equivalent of the useful refrigeration, represented by the area below H S or h H S s.

$$C_e = \frac{Q_u}{Q_w} = \frac{\text{h H S s}}{\text{G H S K D C B}}.$$

These various heat values are determined as follows:

Heat entering $= Q_2 =$ g G H S K d.

g G H S K d = g G H h + h H S s + s S K d.

$$\text{g G H h} = S(T_G - T_H) - T_G\, S \log_e \frac{T_G}{T_H}.$$

$$\text{h H S s} = L_s - (l_G - l_H) = L_s + l_H - l_G.$$

$$= H_s - l_G.$$

$$\text{s S K d} = S(T_s - T_K).$$

Heat rejected $= Q_1 = g\ G\ B\ C\ D\ d.$

$$g\ G\ B\ C\ D\ d = g\ G\ B\ b + b\ B\ C\ c + c\ C\ D\ d.$$
$$g\ G\ B\ b = l_B - l_G.$$
$$b\ B\ C\ c = L_C.$$
$$c\ C\ D\ d = S\ (T_D - T_C).$$

Work of compressor:

$$Q_w = Q_1 - Q_2.$$

Useful refrigeration:

$$Q_u = h\ H\ Ss = H_s - l_G.$$

Coefficient of performance or coefficient of efficiency:

$$C_e = \frac{Q_u}{Q_w}.$$

CONDITION OF SATURATION.

In case of wet compression, without superheating either at low pressure in the expansion coils or at high pressure in the compressor and condenser, the expansion is limited to a point between H and S, as M. With adiabatic compression the maximum temperature would be reached, say, at W, on the line C B and between the points B and C.

The diagrammatic representations of the various heat values are as follows:

$$Q_2 = g\ G\ H\ M\ w.$$
$$Q_1 = g\ G\ B\ W\ w.$$
$$Q_w = Q_1 - Q_2.$$
$$Q_u = h\ H\ M\ w.$$
$$Q_2 = g\ G\ H\ M\ w.$$
$$= g\ G\ H\ h + h\ H\ M\ w.$$

$g\ G\ H\ h =$ as previously given above.

$$h\ H\ M\ w = l_{TM} + L_M - l_G.$$

$$Q_1 = g\ G\ B\ W\ w.$$
$$= g\ G\ B\ b + b\ B\ W\ w.$$
$$g\ G\ B\ b = \text{as previously given.}$$
$$b\ B\ W\ w = L_W =.$$
$$= (N_M - N_{ITW})T_W.$$
$$= (N_{ITM} - N_{ITW} + N_{LM})T_W.$$
$$= (N_{LM} - (N_{ITW} - N_{ITM}))\ T_W.$$
$$N_{LM} = N_{LTM} \times d.$$
$$N_{ITW} - N_{ITM} = S\ \log_e \frac{T_W}{T_M} \text{ from (2).}$$
$$C_e = \frac{Q_u}{Q_w}.$$

IDEAL REVERSIBLE CYCLE.

It may be of interest to consider the case of the ideal reversible cycle, known as Carnot's cycle, as applied to the process of refrigeration.

The development of this cycle involves four consecutive processes as follows:

1st—Adiabatic compression, corrèsponding to compression in cylinder of the compressor, accompanied by increase in pressure and rise of temperature.

2d—Isothermal compression, corresponding to condensation in the compressor.

3d—Adiabatic expansion, corresponding to expansion in an expansion cylinder (a feature for which an expansion valve is substituted in practice).

4th—Isothermal expansion, corresponding to expansion in the expansion coils of the refrigerator.

The cycle for the steam engine would differ in that the isothermal condensation would take place at the lower temperature and the isothermal expansion at the higher temperature (of boiler), the process being reversed to correspond to these conditions.

DIAGRAM FOR CARNOT'S CYCLE.

The equations for the enclosing lines for the Carnot diagram

all represent straight lines, horizontal for the isothermals and vertical for the adiabatics. These are given herewith.

1st and 3d—Adiabatic compression and expansion.

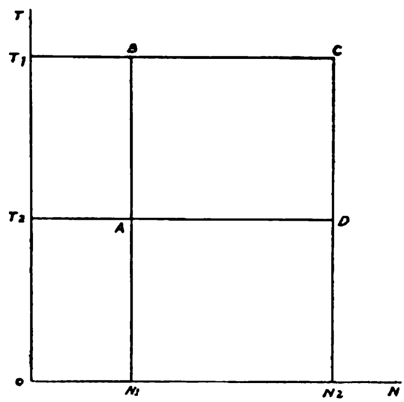
$$\frac{Q}{T} = N = \text{constant, representing a vertical line.}$$

2d and 4th—Isothermal compression and expansion.

$$\frac{Q}{N} = T = \text{constant, representing a horizontal line.}$$

As applied in detail to the diagram shown in Figure 86, the curves are represented as follows:

FIG. 86.



ENTROPY-TEMPERATURE DIAGRAM FOR IDEAL REVERSIBLE CYCLE.

1st—Adiabatic compression, along D C.

$$\frac{Q}{T} = N_{11} = \text{constant.}$$

$$\therefore \frac{Q_D}{T_2} = \frac{Q_C}{T_1} = N_{11}.$$

2d—Isothermal compression, along C B.

$$\frac{Q}{N} = T = \text{constant.}$$

$$\therefore \frac{Q_C}{N_{11}} = \frac{Q_B}{N_1} = T_1.$$

3d—Adiabatic compression, along B A.

$$\frac{Q}{T} = N = \text{constant}.$$

$$\therefore \frac{Q_B}{T} = \frac{Q_A}{T_2} = N_1.$$

4th—Isothermal compression, along A D.

$$\frac{Q}{N} = T = \text{constant}.$$

$$\therefore \frac{Q_A}{N_1} = \frac{Q_D}{N_{11}} = T_2.$$

Q_2 = area below A D.

Q_1 = area below C B.

$Q_w = Q_1 - Q_2.$

$Q_u = Q_2.$

Q_2 = area below A D.

$= Q_D - Q_A = N_{11} T_2 - N_1 T_2 = T_2 (N_{11} - N_1).$

$Q_D = N_{11} \times T_2.$

$Q_A = N_1 \times T_2.$

Q_1 = area below C B.

$= Q_C - Q_B = N_{11} \times T_1 - N_1 \times T_1 = T_1 (N_{11} - N_1).$

$Q_C = N_{11} \times T_1.$

$Q_B = N_1 \times T_1.$

$Q_w = Q_1 - Q_2 = T_2 (N_{11} - N_1) - T_1 (N_{11} - N_1).$

$= (T_2 - T_1)(N_{11} - N_1).$

$Q_u = Q_2 = T_2 (N_{11} - N_1).$

$$C_e = \frac{Q_u}{Q_w} = \frac{T_2 (N_{11} - N_1)}{(T_2 - T_1)(N_{11} - N_1)} = \frac{T_2}{T_2 - T_1}.$$

The expression just given for the coefficient of performance represents the highest efficiency obtainable for a given range of temperature.

CALCULATION FOR COEFFICIENT OF PERFORMANCE.

A complete set of calculations for an assumed set of conditions will serve to illustrate the application of the principles that have been elaborated.

DATA.

The minimum temperature to be maintained in the system would follow from the temperature to be maintained in the refrigerator, being from 15° to 20° F. lower than the latter. Accordingly, with a desired temperature in the refrigerator of 18° to 20° F., we would have for our first value approximately

$$t_H = 2° \text{ F.}$$

Data corresponding to $t_H = 2°$ F.

$$T_H = t_H + 460.7 = 462.7 = T_M = T_S.$$
$$P_H = 31.84 \text{ lbs. per sq. in.}$$
$$l_H = l_S = l_M \text{ heat of liquid for } T_H = 2 \text{ B. T. U.}$$
$$L_S = \text{latent heat of vaporization} = 554.27 \text{ B. T. U.}$$
$$H_S = l_S + L_S = 556.27 \text{ B. T. U.}$$
$$N_{1TH} = S \log_e \frac{T_H}{T_0} = 1 \times \log_e \frac{462.7}{460.7} = 0.004324.$$
$$N_{LS} = \frac{554.27}{462.7} = 1.198.$$

The condenser temperature and temperature of the liquid are likewise features that are dependent upon existing conditions, the minimum being a few degrees higher than the temperature of the condenser water, the difference being dependent upon the style and efficiency of the condenser, and whether or not a liquid fore-cooler is used. While in some cases with a good condenser, the difference may be as low as 5° F.; in most cases, with an atmospheric condenser, the difference would be more likely to be near 15° F. With liquid fore-cooling this difference may be reduced to about 3° F.

We will assume that these latter conditions prevail, and that with condensing water at 75° F., we have further data for our problem as follows:

$$t_B = 85° \text{ F.}$$
$$t_G = 73° \text{ F.}$$

Data deduced from

$t_s = 85° F.:$

$T_s = 545.7° F. = T_w = T_c.$
$P_s = 167.88$ lbs. per sq. in.
$l_s = 85$ B. T. U.
$L_c = 501.81$ B. T. U.

$$N_{TH} = S \log_e \frac{T_B}{T_0} = 1 \times \log_e \frac{533.7}{460.7} = 0.179.$$

$$N_{LTC} = \frac{501.81}{545.7} = 0.9194.$$

$$N_C = 0.179 + 0.9194 = 1.0984.$$

Data deduced from

$t_G = 73° F.:$

$T_G = 533.7° F.$
$l_G = 73$ B. T. U.
$P_G = 122.5$ lbs. per sq. in.

$$N_G = S \log_e \frac{T_G}{T_0}.$$

TEMPERATURE OF SUPERHEAT AT LOW PRESSURE.

In some cases of actual tests the ammonia entering the compressor has been found to be superheated from 14° to 37° F. The actual superheating due to the interior walls, piston and passageways must have been considerably in excess of these values given. We will assume the total temperature of superheat to be about 40° F. Accordingly $t_K = 2 + 40 = 42°$ F.

The entropy N_K is obtained from the formula for the line S K, using S = .52 for the value for specific heat of ammonia at constant pressure.

Data deduced from

$t_K = 42° F.:$

$T_K = 502.7° F.$

$$\begin{aligned} N_K &= N_{ITH} + N_{LTS} + (N_K - N_S) \\ &= 0.004324 + 1.198 + 0.043167 \\ &= 1.2455. \end{aligned}$$

$$N_K - N_S = S \log_e \frac{T_K}{T_S}$$
$$= .52 \log_e \frac{502.7}{462.7}$$
$$= 0.043167.$$

The point of highest temperature is that for superheating on the high pressure side at D. The value for this temperature is obtained from the formula for the curve C D, using in the same the value for entropy of D = N_D, the value obtained for K, for the reason that $N_D = N_K$.

Determination of T_D.

$$N_D = N_K = 1.2455.$$
$$N_C = 1.0984.$$
$$N_D - N = 0.1471.$$
$$N_D - N_C = S \log_e \frac{T_D}{T_C} = S \log_e T_D - S \log_e T_C.$$
$$\log_e T_D = \frac{N_D - N_C}{S} + \log_e T_C.$$
$$\frac{N_D - N_C}{S} = 0.283.$$
$$\log_e T_C = 6.29499.$$
$$\log_e T_D = 6.57799.$$
$$T_D = 728° \text{ F}.$$

DATA IN REGARD TO SPECIFIC HEAT OF AMMONIA.

For specific heat of liquid use S = 1.00. This value is somewhat low, but will serve for approximate results.

Various values are given for the specific heat of liquid, ranging from 1.00 to 1.10, or even higher.

Specific heat of vapor at constant pressure S = 0.52.

Data required occasionally are the following:

Specific heat of vapor at constant volume S = 0.40.

$$\text{Ratio of specific heats: } \frac{S_p}{S_v} = \frac{0.52}{0.40} = 1.30.$$

INITIAL TEMPERATURE FOR HEAT VALUES AND ENTROPY.

Assume the initial temperature from which heat and entropy are determined to be $t_0 = 0°$ F., ∴ $T_0 = 460.7°$ F.

SOLUTION OF PROBLEM.

The essential points having been determined, we will attempt to employ them to the end to obtain the final solution.

$$Q_2 = g\,G\,H\,h + h\,H\,S\,s + s\,S\,K\,d$$

$$g\,G\,H\,h = S\,(T_G - T_H) - T_G\,S\,\log_e \frac{T_G}{T_H}.$$

$$= 71 - 76.11 = -5.11.$$

(Negative sign does not affect value, as it indicates direction only.)

$$h\,H\,S\,s = H_S - l_G = 483.27.$$

$$s\,S\,K\,d = S\,(T_K - T_S) = 20.8.$$

$$Q^2 = 5.11 + 483.27 + 20.8 = 509.61.$$

$$Q^1 = g\,G\,B\,C\,D\,d.$$

$$g\,G\,B\,b = l_B - l_G = 12.$$

$$b\,B\,C\,c = L_C = 501.81.$$

$$c\,C\,D\,d = S\,(T_D - T_C) = 94.796.$$

$$Q_1 = 12 + 501.81 + 94.796.$$

$$= 596.606.$$

$$Q_u = h\,H\,S\,s = H_S - l_G = 483.27.$$

$$H_S = 556.27.$$

$$l_G = 73.$$

$$Q_W = Q_1 - Q = 596.606 - 509.61.$$

$$= 86.996.$$

$$C_e = \frac{Q_u}{Q_W} = \frac{483.27}{86.996} = 5.56.$$

CALCULATION FOR CONDITION OF SATURATION.

In case of wet compression, without superheating either at low pressure in the expansion coils or at high pressure in the

compressor and condenser, the expansion is limited to a point between H and S, as M. With adiabatic compression the maximum temperature would be reached, say, at W, on the line C B and between the points B and C.

Let K = degree of wetness at termination of vaporization in per cent.

$= 20$ per cent.

$d = 1 - \frac{K}{100}.$

$= \frac{100 - K}{100} =$ ratio of actual vapor formed to maximum.

$= .80.$

$T_M = T_H = 462.7.$

$L_M = L \times d = 554.27 \times .80 = 443.$

$N_M = N_{ITM} + N_{LM} = N_{ITM} + N_{LXd} = N_{ITH} + N_{LXd}.$

$= N_{ITS} + N_{LTSXd} = .00434 + 1.198 \times .80.$

$= .964324.$

$N_W = N_M = N_{IW} + N_{LW} = N_{IB} + N_{LW} = .1729 + N_{LW}.$

$L_M = L_{TM} \times d = 554.27 \times .80 = 443.$

$N_{LW} = N_M - N_{IW} = .964324 - .1729 = .791424.$

$L_W = N_{LW} \times T_W = .791424 \times 545.7.$

$= 432.3.$

$l_{TM} = l_{TH} = 2.$

$Q_2 = g\,G\,H\,M\,w.$

$Q_1 = g\,G\,B\,W\,w.$

$Q_W = Q_1 - Q_2.$

$Q_u = h\,H\,M\,w.$

$Q_2 = g\,G\,H\,M\,w.$

$= g\,G\,H\,h + h\,H\,M\,w.$

$g\,G\,H\,h =$ as previously given $= 5.11.$

$h\,H\,M\,w = l_{TM} + L_M - l_G.$

$= 2 + 443 - 73.$

$= 372.$

$Q_2 = 5.11 + 372 = 377.11.$

$$
\begin{aligned}
Q_1 &= g\,G\,B\,W\,w. \\
&= g\,G\,B\,b + b\,B\,W\,w. \\
&\quad g\,G\,B\,b = \text{as previously given} = 12. \\
&\quad b\,B\,W\,w = L\,W = 432.3. \\
Q_1 &= 12 + 432.3. \\
&= 444.3. \\
Q_u &= h\,H\,W\,w. \\
&= 372. \\
Q_w &= Q_1 - Q_2. \\
&= 444.3 - 377.11. \\
&= 67.19. \\
C_e &= \frac{Q_u}{Q_w} = \frac{372}{67.19} = 4.935.
\end{aligned}
$$

CALCULATION FOR IDEAL REVERSIBLE CYCLE.

For the problem in hand the value for the maximum efficiency would be determined as follows:

T_2 corresponds to the temperature to be maintained in the refrigerator—assumed to be 18° to 20° F. At $t_2 = 20°$ F. we would have $T_2 = 480.7$.

T_1 would correspond to the highest temperature, which represents the temperature of the surroundings. This would correspond closely to the temperature of condensing water. This was taken at 70° F. Accordingly we will assume $T_1 =$ 540° F.

$$C_e = \frac{T_2}{T_1 - T_2} = \frac{480.7}{540.7 - 480.7} = \frac{480.7}{60} = 8.01.$$

The result just obtained for the coefficient of performance represents the maximum value obtainable for the assumed conditions of the problems.

PART II.

PRACTICE AS SHOWN BY PARTICULAR SYSTEMS AND APPARATUS.

The practical features of refrigeration, as exemplified by the apparatus in use and on the market, are the result of years of progressive development, involving extensive study and expenditure. New ideas are welcomed and tried on their merits, and there is at the same time a conservative regard for the old and reliable methods that were the basis of past successes. Consequently it is to be expected that there is in use a large variety of apparatus and devices. Individual manufacturers indeed offer a considerable variety from which to choose, and do not confine themselves to any particular combination to make up a so-called system. For the reasons given it is a large task to undertake to cover the whole field, and in doing so it is hardly possible to do full justice to any particular system. Accordingly in the following pages it is intended to limit ourselves to bringing out the characteristic features of the different classes of apparatus that are in actual use, without desire to favor the product of any particular manufacturer.

CHAPTER I.

THE AMMONIA COMPRESSION SYSTEM—HUMID COMPRESSION.

The Linde ice machine is operated as a strictly humid or wet-compression machine. This machine, the invention of Prof. C. P. G. Linde, formerly of the University of Munich, Germany, has been in active operation in forty-nine countries of the globe. The machine brought out by Prof. Linde was the first ammonia compression ice machine of practical value.

Between the years 1875 and 1881 there were thirty machines built. Up to 1890 possibly 1000 machines had been built. During the years that have elapsed since that time, the number has run up into thousands.

The first machine in the United States, a 25-ton machine, was erected in 1880, and has been in constant operation since.

This type of machine is put on the American market by the Fred W. Wolf Co. of Chicago, and the American Linde Refrigerating Co. of New York. The product of the former will be considered in the present instance.

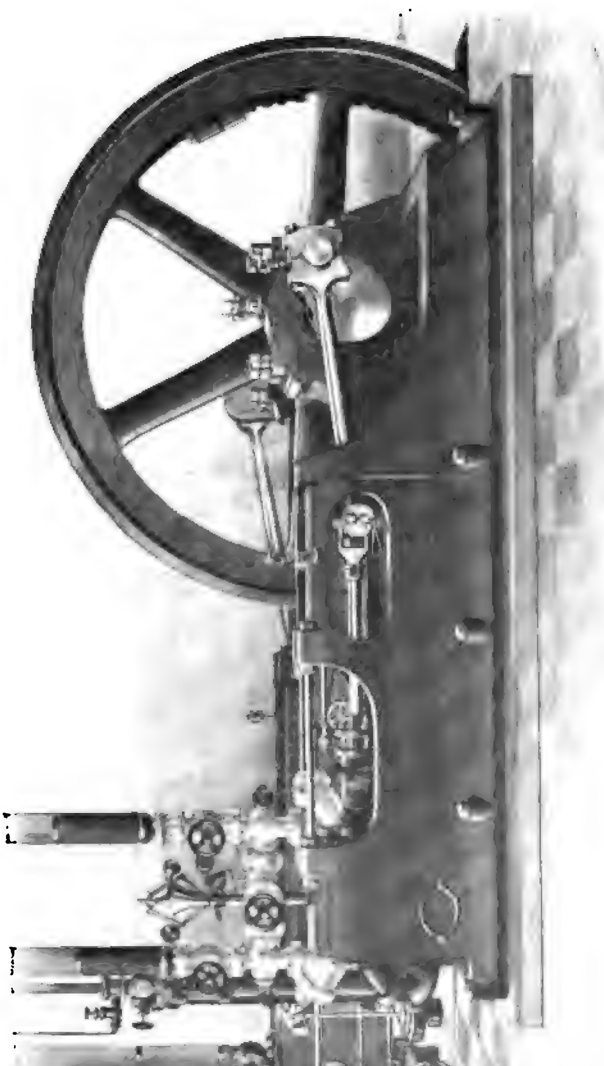
SOME OF THE PARTS OF A LINDE PLANT.

THE COMPRESSOR.

The compressor is of the horizontal double-acting type. An exterior view is shown in Fig. 87, and a sectional view of the compressor cylinder is shown in Fig. 88.

It will be observed that the piston and heads are spherical and of the same radius. The valve discs conform to this radius, and when the valves are seated these discs are flush with the heads. By careful construction the space between the head and piston at the end of the stroke is reduced to one thirty-second of an inch or less. There are no pockets formed by the valve ports. This design and construction reduces

Fig. 87.



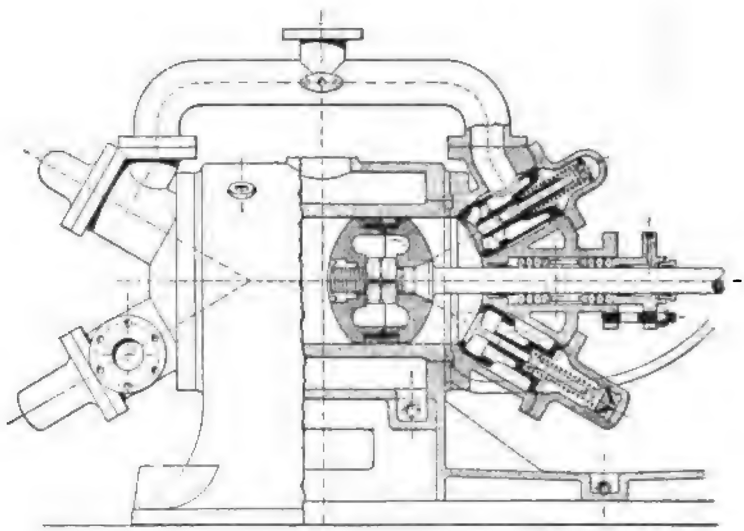
THE COMPRESSOR—HORIZONTAL DOUBLE-ACTING

Fred. W. Wolf Co.

clearance losses to the minimum. The cylinders are made of clear, hard iron, tested to 1,000 lbs. hydrostatic pressure. The finishing cut through the cylinder is made after it is placed in the frame, the final cut on crosshead guides being taken at the same time, and on the same boring bar, thus insuring their correct alignment. Proper openings are provided for the application of the indicator.

As the machine operates strictly under humid or wet compression, no water jackets or auxiliary cooling devices are pro-

FIG. 88.



A SECTIONAL VIEW OF THE LINDE COMPRESSOR.

vided for keeping the temperature of the cylinder walls and piston within proper limits. This feature is taken care of by the particles of liquid brought over into the cylinder with the saturated vapor.

The stuffing-box is an extremely important feature of the compressor, and has received attention commensurate with its importance. The result is a highly developed article, which has been described in detail in Part I, Chapter XVIII, and shown in section in Fig. 78.

AMMONIA CONDENSERS.

THE ATMOSPHERIC CONDENSER.

The atmospheric condensers, Fig. 31, are constructed of two-inch pipe made from specially selected skelp.

The pipes are put together with forged Bessemer steel flanges and semi-steel return bends.

These flanges are tapped smaller than the pipe to which they are to be attached. While hot, and therefore expanded, they are screwed on the pipe. The flange, in cooling, contracts with enormous force. The recess at the back of the flange is then flushed with solder, making the most perfect joint known. These flanges are faced male and female.

The flanges of the return bends are similarly faced and corrugated lead gaskets inserted. The drawing up of the four bolts makes the quickest, tightest and most rigid connection possible.

To remove a length of pipe it is only necessary to loosen the four bolts at each end, when a new pipe can easily be put in place in a very little time, the flanges being interchangeable. These flanges are joined with a recessed joint packed with corrugated soft metal or rubber gaskets.

The condensers have galvanized water troughs with leveling device, and have perforated drip strips between the pipes. By means of these perforations a free circulation of air is obtained, resulting in an increased efficiency of the cooling water.

When the condenser consists of more than one section, each section is provided with a stop-valve on both inlet and outlet, so that any section can be shut off without interfering with the continued operation of the remaining sections.

An auxiliary header, having stop valve on each section, is also provided. When connected with the suction of the compressor, the ammonia can be pumped out of any section through this header, without interfering for a moment with the operation of the remaining sections.

These condensers are tested to 500 lbs. air pressure before leaving the shops and are guaranteed tight.

DOUBLE PIPE CONDENSER.

The construction of this type of condenser, Fig. 36, corresponds, so far as is applicable, to that employed in the condensers of the atmospheric type. Straight lengths of special ammonia pipe are used, to which are shrunk and soldered forged-steel flanges. These in turn are bolted to the flanges of the ammonia return bends. This permits the removal and replacing of any pipe without dismantling the whole apparatus, as is the case whenever double-pipe condensers are made up with center connections and screwed return bends.

These condensers are usually twelve pipes high. The two upper pipes are 2½ inches in diameter and the ten lower 2 inches. The water pipe is 1¼ inches throughout. The use of larger pipes at the top gives a wider annular space between the external surface of the water pipe and the internal surface of the ammonia pipe, providing the greater space which is required for the gas when it first comes into the condenser, owing to its rarified condition. As soon as the cooling influence of the water becomes effective and the ammonia becomes denser, less space is of course required.

By dispensing entirely with center connections there is obtained a perfect counter-current of the ammonia and water throughout their respective courses through the condenser. The coldest water is, therefore, brought in contact with the liquefied ammonia. It is found that the temperature corresponding to the pressure of the ammonia entering the top pipe of the condenser is only slightly higher than that of the water coming out, showing that the greatest possible efficiency was obtained from the water.

THE OIL TRAP.

The oil trap is connected in the discharge conduit between the compressor and the condenser, and is for the purpose of holding any lubricating material that may pass out from the compressor.

THE LIQUID AMMONIA RECEIVER.

The liquid ammonia receiver, Fig. 58, is of heavy pat-

tern, provided with glass gauges, shut-off cocks, and with inlet and outlet valves and draw-off cocks for the ammonia. The receivers are made of either wrought steel or semi-steel, with welded heads or with screwed and soldered heads. They are tested to one thousand pounds per square inch. The valves are of the needle-point pattern, and automatically close in case the gauge glass should become broken, thereby obviating the danger of loss of ammonia.

DESCRIPTION OF A PLANT.

The Linde Compressor is of the double-acting type, and so constructed that either end of the cylinder can be attached separately to any part of the plant, whereby each works independently of the other, in reality making two single-acting cylinders.

The ammonia gas is drawn into the compressor through the suction valve situated at the upper part of the cylinder head, compressed, and forced out through the discharge valves situated at the lower point of the cylinder.

The compressed gas then passes through the oil trap, where any lubricating oil from the compressor which it may contain is deposited, into the condenser. This oil can be drawn from the tap and used again and again to lubricate the stuffing-box of the piston.

Between the compressor and the oil trap is a check valve, the duty of which is to prevent loss of gas in case of accident to the compressor.

The construction of the condenser is such that the warm compressed gas enters at the top pipe and passes downward through the successive pipes of the condenser, and by the combined influence of the pressure produced by the compressor, and the cooling influence of the cold water running over the pipes of the condenser, becomes liquefied. The liquid ammonia is then discharged into the liquid receiver, generally situated in the engine room, where it is stored and re-stored for further use.

DIRECT EXPANSION SYSTEM.

In the direct expansion system the liquid ammonia passes directly from the receiver to the cellars, storage rooms, chill rooms, ice-making tank, or wherever else the work of cooling is to be done, and there expands to its original gaseous form, this expansion of the liquid ammonia performing the actual work of refrigeration.

The expanded gaseous ammonia is then drawn back into the compressor, and sent again and again on the same round of operation as before described.

In Fig. 89 is shown a diagram of a direct expansion brewing plant.

The pipes in the cellars or cooling rooms are divided into coils of from 300 to 1,500 feet in length, and each coil is provided with a valve for regulating the flow of ammonia into the coil, and also with a valve for shutting off the return. The return pipes from all these coils in the cellars are joined to one main pipe, at the lowest point of which is placed a small trap or receptacle, the duty of which is to catch all scale, bits of dirt, etc., that may pass through the coils, which, if allowed to go in the compressor, would injure the valves.

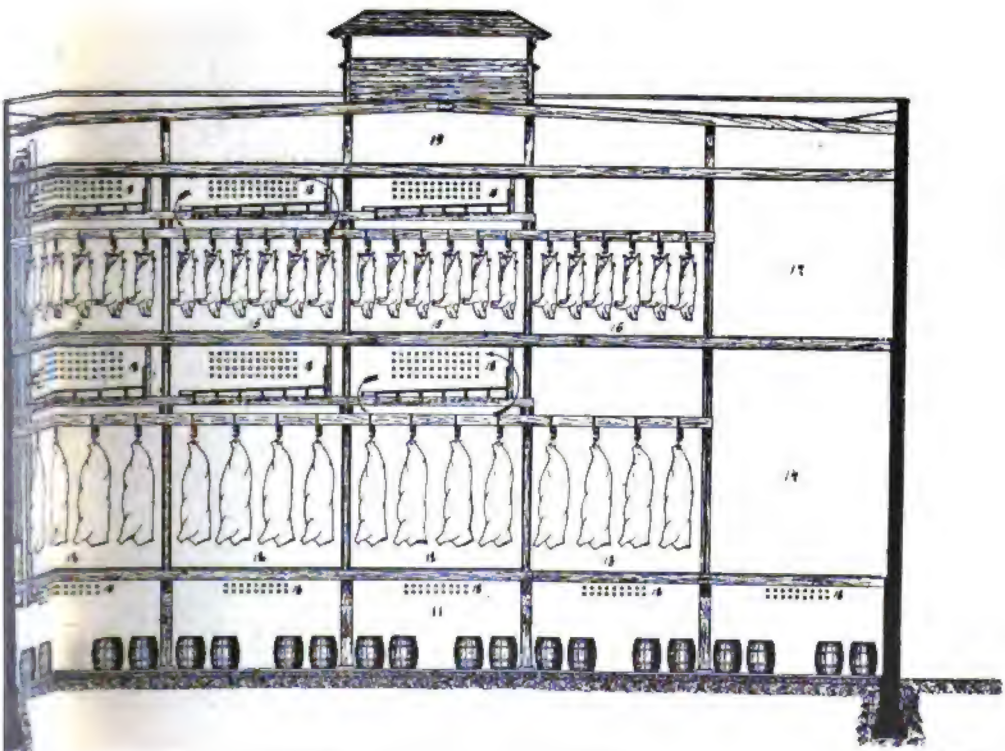
All the pipes in which the ammonia is circulated are wrought iron, made especially for the purpose and joined in the most perfect and solid manner, thereby obviating all danger of loss of ammonia by leakage.

BRINE SYSTEM.

In some cases and for particular purposes the Brine System (Fig. 90 and Fig. 4,) is used instead of direct expansion. In this case, the ammonia, instead of evaporating in the cooling rooms, evaporates in several sets or nests of coils placed in a large, well insulated iron or wood tank. These tanks are filled with a strong solution of salt which can be cooled to the desired temperature. The process of liquefying the ammonia and its circulation in the evaporating coil is practically the same as described for the direct system.

The solution of salt (brine) is circulated by means of a brass

FIG. 90.



ACKING AND COLD STORAGE HOUSES. INCLUDING STEAM PLANT.

(To face p. 200.)

lined and brass fitted pump through a series of pipes in the rooms to be cooled. These pipes (preferably 1¼ in. diameter) are arranged in coils of suitable lengths, having a valve at inlet and outlet so that each coil may be shut off entirely. These coils are of such a length as may be required for the work to be performed, the usual length being from 300 to 600 feet, and are so arranged that the temperature of the rooms may be properly regulated.

The brine, after having passed through the proper number of feet of pipe in the cooling rooms, returns to the brine tanks in the machine room again to be cooled. Fig. 4 shows two different arrangements of piping for chilling rooms. The arrangement shown in the upper room is preferable to the other unless restricted by want of space. In cold storage and freezing rooms the pipes may be arranged on the ceiling or on the wall, whichever may be most convenient for the purpose intended.

ICE PLANTS.

Fig. 91 shows the arrangement of a complete ice factory for the production of ice from distilled water.

The steam generated in the boiler is first used to drive the steam engine. It then passes through the exhaust pipe to the steam purifier and grease extractor, where any oil or other lubricating material used in the cylinder of the engine likely to be detrimental to the ice is removed. The steam then passes into the steam condenser, which is designed on the same principle as that of the atmospheric ammonia condenser, in which the steam is condensed and passes to the skimming tank, where any oil that may have passed through the steam purifier is entirely removed. Other constructions of steam condensers may be used where desirable, on account of local conditions.

The water resulting from the condensed steam passes down to the reboiler, at the bottom of which is placed a small coil. This coil is supplied with a small quantity of live steam from the boiler, by means of which the water is kept boiling and the air contained in it expelled; and, as the steam which

is used to drive the engine may not be quite sufficient to make water for the full quantity of ice, live steam is introduced to the steam condenser to supply the deficiency. From the reboiler the water passes through the cooling coil and from thence to the filters. These filters are usually furnished in duplicate, so that one may be shut off and cleaned out while the other is running. Sponge filters or bone charcoal filters are used where the nature of the water renders them necessary. From the filter the water passes to the cold storage tank, containing a direct expansion coil connected with the machine, where the distilled water is cooled to almost freezing temperature and stored until again used.

From the storage tank the distilled water is filled into the cans placed in the freezing tank by means of an automatic can filler. This is so constructed as to automatically shut off the water-supply when the can is filled to the proper height, thus requiring no attention, and avoiding the annoyance of filling the can to overflowing with its resulting waste of distilled water. This is an important item constantly to be borne in mind.

The freezing tank is made of iron or steel, and contains the direct expansion freezing coils equally distributed throughout the tank. These coils are submerged in brine, consisting of a solution of common salt. The tank is also provided with a suitable frame of hard wood for supporting the ice cans, and a propellor or agitator for keeping the brine in motion. The brine in the tank acts as a medium of contact only; the ammonia evaporating in the freezing coils extracting the heat from the brine, which again absorbs the heat from the water in the cans, thereby freezing it.

The compression and condensation of the ammonia takes place in the same manner as described heretofore.

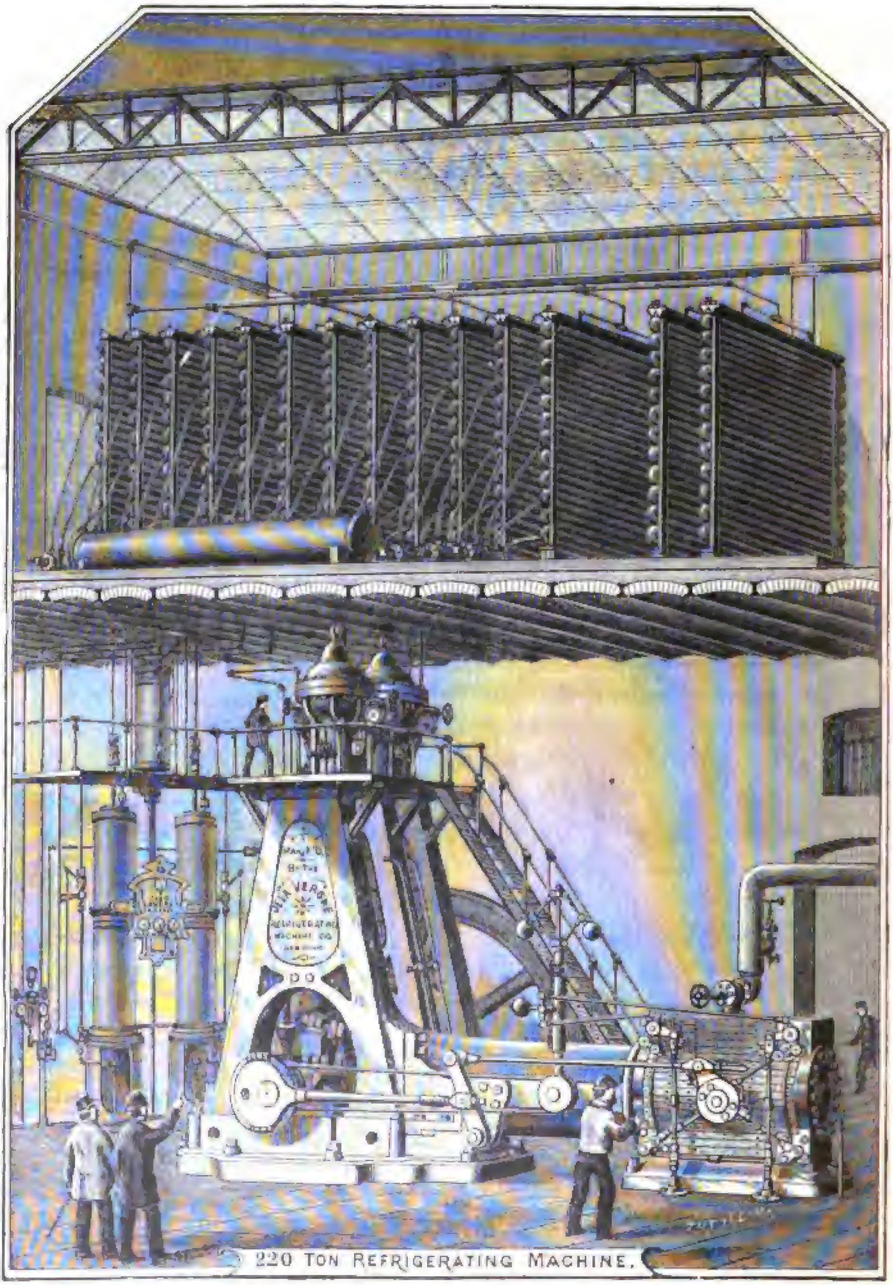
The hoisting apparatus is strong and easily movable, and so constructed that a can of ice can be delivered from any part of the tank to the thawing apparatus with ease by one man.

The thawing apparatus usually furnished consists of either a bath of warm water (from the steam condenser) into which

the cans are immersed, or an automatic sprinkling and dumping apparatus into which the cans are placed, and, when loosened, discharged into the storage rooms.

The ice plants are constructed with a view to rigid economy in the use of water, it being first used on the ammonia condenser, then on the cooling coil, then on the steam condenser, and finally, when quite warm, used to feed the boiler, thereby performing multiform work besides reducing the expense of heating the boiler feed-water.

FIG. 93.



De La Vergne Machine Co.

CHAPTER II.

THE AMMONIA COMPRESSION SYSTEM WITH OIL INJECTION. DE LA VERGNE SYSTEM.

By oil injection is meant the injection of oil in the cylinder in comparatively large quantities after the cylinder has received its complement of gas or vapor and compression has begun. The compression space is literally flooded with oil so as to completely fill all clearance spaces, and require the discharge of some of the oil with the compressed gas.

The purpose of this oil injection, in addition to sealing the clearance spaces, is to seal the piston and piston-rod, eliminating leakage at these parts; lubrication of the piston and piston-rod, reducing friction losses; and absorption of heat of compression, avoiding excessive temperature without water jacket.

These purposes are for the most part realized. The effectiveness of the filling of clearance spaces is to some extent nullified by the fact that under the high pressure considerable quantities of ammonia gas are absorbed by the oil, which gas is released and expands during the suction period, occupying space in the cylinder to the exclusion of a corresponding amount of suction vapor or gas, and thereby reducing the capacity of the compressor.

The liberal use of oil in the manner described permits of a free adjustment of the moving parts, and a consequent increase in life of the same without undue losses from friction or leakage of ammonia. As the oil is admitted after the suction port has been closed there is no diminution of the capacity of the compressor due to the oil injection.

The use of oil injection is confined to vertical compressors. Machines are, however, made double-acting.

Some complication is involved in the compressor and in special arrangements for separation of the oil from the ammonia. These features involve extra cost for the preliminary

outlay. Years of continuous service demonstrate the reliability of the apparatus in practical operation.

The system of oil injection was developed by the De La Vergne Machine Co., of New York, which company also produces horizontal compressors and other machines operating without oil injection. The machine operating with oil injection is known as the Standard Compressor.

THE STANDARD COMPRESSOR.

The Standard Compressor, Fig. 76, is a vertical double-acting machine. The arrangement of the valves is special to provide for the oil circulation. The valves are all spring valves, closed by coil springs. The suction valves are ordinary in number, one for each end, and are located in the suction passage near the ends of the cylinder. The upper discharge valves are located at the end of the piston in the loose head, the head being removable. The valves are of ample area to allow for the discharge of the oil as well as the gas. The upper end of the piston is essentially flat. The construction and operation of the suction valves and the upper discharge valves and the upper portion of the cylinder and piston, although involving certain peculiarities, may in a general sense be classed as ordinary.

In the lower portion of the cylinder the operations are out of the ordinary, and involve a special construction. See Fig. 94. For the discharge of gas alone, at least the greater part, ordinary construction would suffice. On account of the presence of the oil, however, especially in quantity superfluous for simply sealing the clearance spaces, outlet for this oil must be provided. This is accomplished by having two discharge valves, at the lower portion of the cylinder, one above the other. These valves are located at the side of the cylinder to enable a complete discharge of free gas to be obtained.

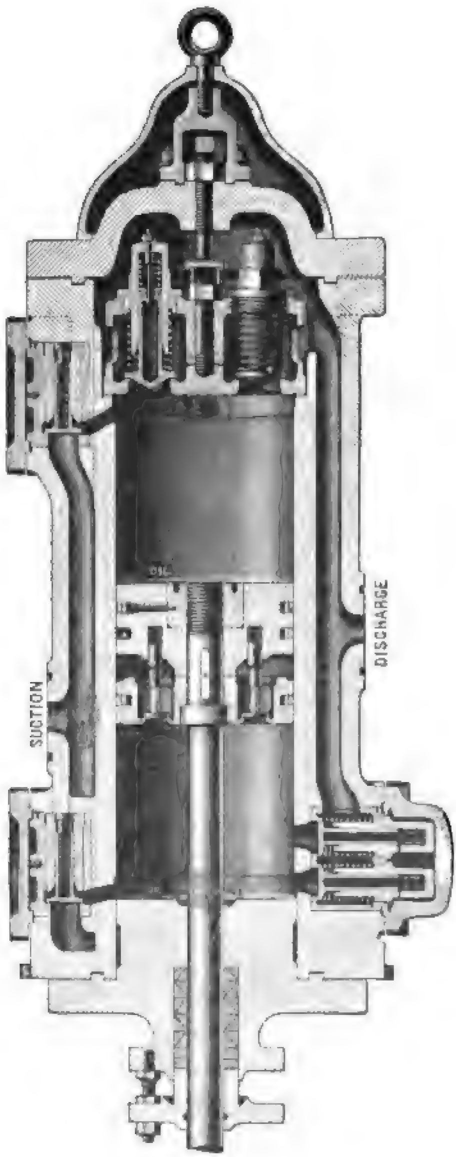
In the piston there are orifices leading from directly below over to the side of the piston. These orifices, which are ordinarily closed by valves, connect near and at the end of the stroke from the space below the piston to the upper of the

two discharge valves. By this arrangement it will be seen that there is continuous connection between the cylinder space and the discharge chamber, in spite of the fact that the piston obstructs at times both valve openings in its passage. During the greater part of the compression both valves are free to operate.

During the latter part they are obstructed, though in succession. While the upper valve is obstructed by the lower part of the piston, the lower one is free to operate. Before the lower valve is obstructed, however, the upper valve is connected to the cylinder space by means of the orifice or passage in the piston that has been mentioned.

In spite of the presence of a liquid at the final discharge, machines of this type are adjusted with as small a clearance as could reasonably be desired of any machine whatsoever, and when so adjusted can be run safely at high speed.

FIG. 94.



SECTIONAL VIEW OF DOUBLE-ACTING VERTICAL COMPRESSOR.

THE FORE-COOLER.

The fore-cooler is a necessary feature of the system that has been described. Its function is by cooling to remove the oil, or at least the greater part of the same, from the ammonia. It is practically a diminutive condenser, the mixture of oil and ammonia gas or vapor being passed through a pipe coil system over which flows cooling water. The discharge from the fore-cooler passes to the pressure tank, where the oil is deposited, the ammonia vapor passing on to the condenser.

AMMONIA CONDENSER.

While any of the various styles of condensers may be used, as the double-pipe condenser or atmospheric condenser, preference is generally given, where the conditions warrant the same, to the special atmospheric condenser, known as the Standard Condenser, described in Chapter VIII and shown in Fig. 32.

This condenser, with ordinary temperatures, is built of five sections of 18 two-inch pipes 20 feet in length. Where abnormally warm condenser water must be used it is built up 24 pipes in height.

The condensers are all built of special selected wrought iron lap-welded ammonia pipe, the fittings being of the screwed and soldered joint pattern. They are tested under hydrostatic pressure of 1000 pounds per square inch.

EXPANSION COCK AND RADIATING DISK.

The De La Vergne pattern of these parts has already been shown, the expansion cock in Figs. 50, 51 and 52 and the radiating disk in Fig. 39.

CYCLE OF OPERATIONS IN REFRIGERATION.

In the complete cycle of operations in a refrigerating plant the parts of the system are respectively the compressor, the fore cooler, the oil separator, the condenser, the liquid ammonia storage tank, and the expansion coil. A source of motive power is of course understood to be on hand. The

mediums used are steam for the motive power, water, ammonia and oil.

The water cools the pipes of the fore cooler and the condenser. The circuit of the oil is from the compressor through the fore cooler, the oil separator and back to the compressor. The cycle for the ammonia is, starting as a gas from the compressor, through the fore cooler and oil separator to the condenser, where it is condensed to the liquid state, thence to the liquid storage tank, from which it is admitted to the expan-

FIG. 95.

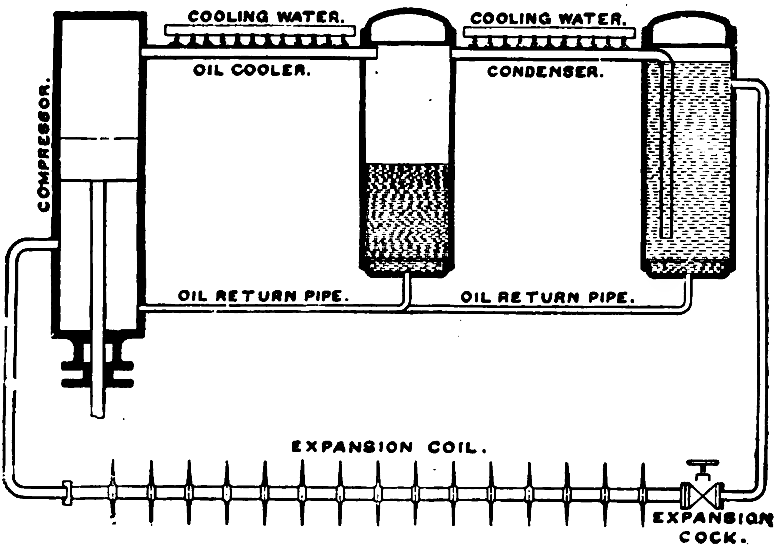


DIAGRAM OF A REFRIGERATING PLANT.

sion coils through the expansion cock. From the expansion coils it returns to the compressor, thus completing the cycle.

These cycles may be followed by a reference to the diagrams Figs. 95, 96, 97 and 98.

ICE-MAKING.

In general the can system of ice-making is the one advocated. In the production of ice capable of fulfilling the demands, a number of details are involved which, while tending

to complication, are indispensable to the most economical results. The process could be simplified and ice produced more cheaply, but it would not be as clear or as pure as by the methods adopted. The methods of obtaining the best are the ones that will be mentioned.

Fig. 96.

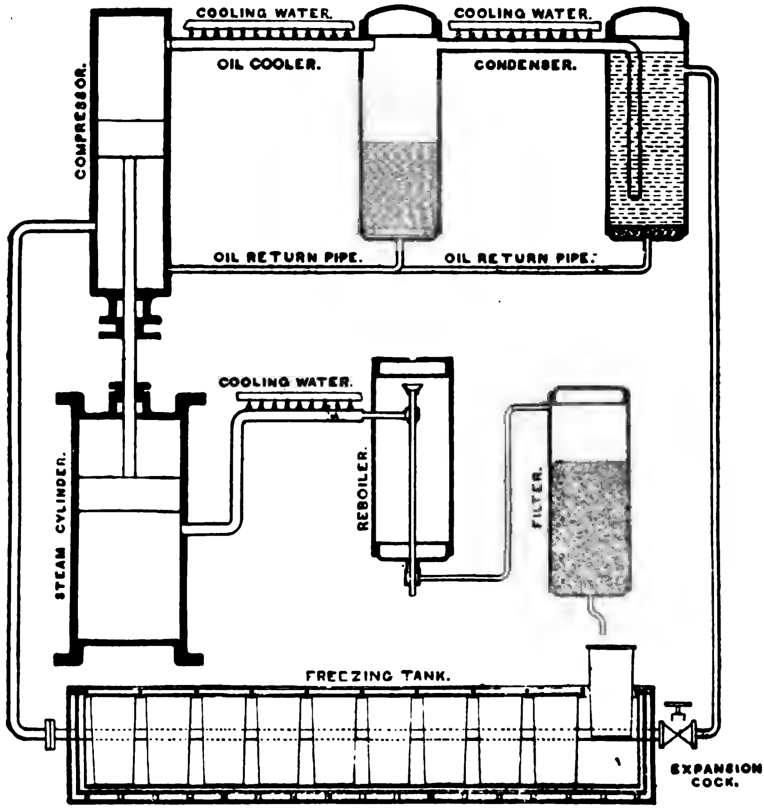
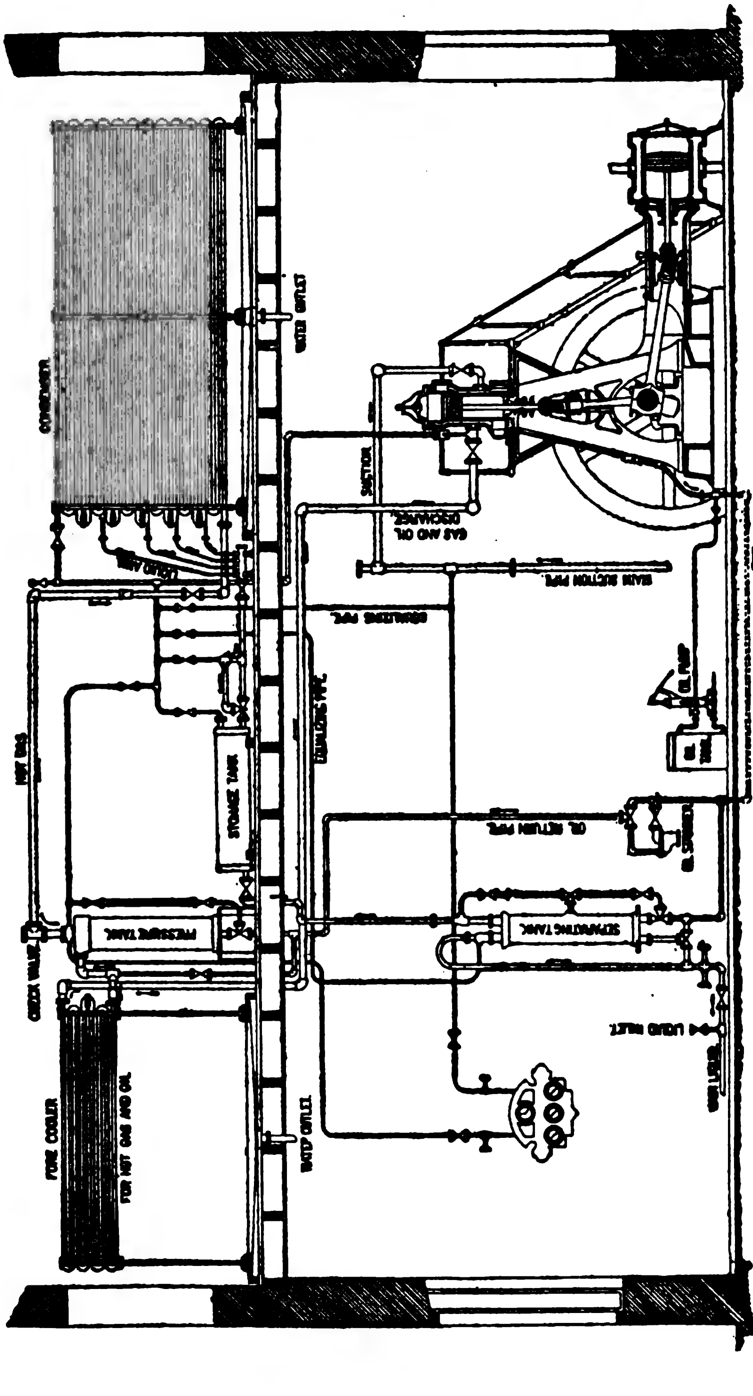


DIAGRAM OF AN ICE PLANT.

In describing the cycle or cycles of operations for an ice plant as carried out in practice, the steam part of the plant is brought prominently into the system, as the condensed exhaust steam is used to supply a part of the water from which the ice is made.

FIG. 97.



STANDARD COMPRESSOR.
Diagram of De La Vergne Refrigerating Plant with Standard Compressor.

The parts of the system shown in diagram, Fig. 98, are the boiler plant, steam engine, compressor, fore-cooler, oil separator, condenser, storage tank for liquid ammonia, expansion cock, expansion coils, steam filter, condensed water cooler, reboiler, filter or deodorizer, cold water storage tank, and freezing tank.

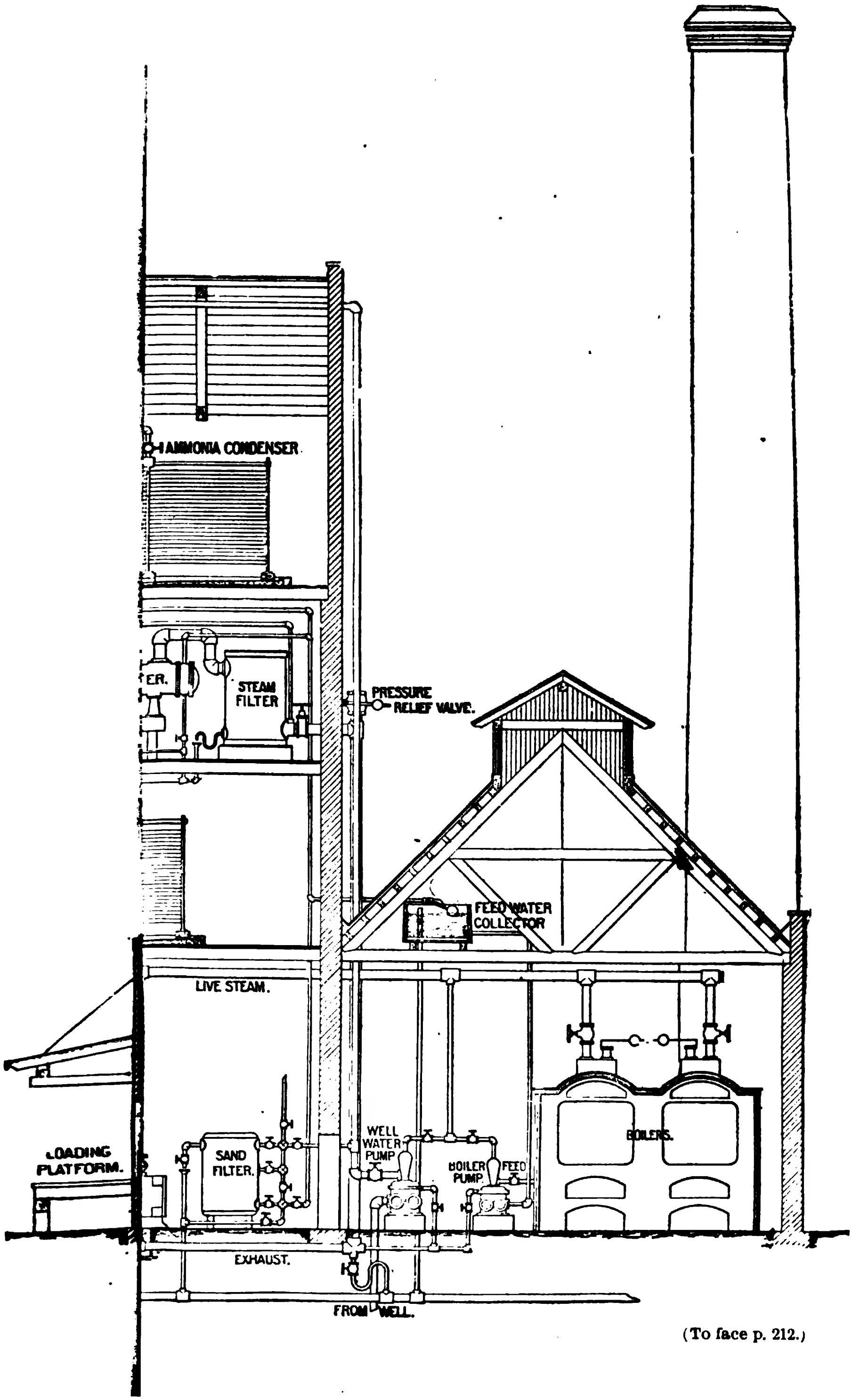
The mediums used are steam, water, brine, oil and ammonia. The disposition of the parts and the course of the mediums that pertain to the refrigerating part of the plant will accord with the description already given for these. The additional features will be mentioned here.

The brine is used in the freezing tank as a medium for the transfer of the heat from the expansion coils to the freezing cans. The exhaust steam travels from the cylinder through a steam filter and feed-water heater to the steam condenser, thence to the reboiler, passing from the reboiler to the filter, from which it goes to the cold water storage tank, ready to be drawn off into the cans. The office of the reboiler is to drive impurities to the top, and to drive out the air. A skimmer carries off the scum, and the air passes out at the top, the cleansed water being drawn off at the bottom.

DESCRIPTION OF AN ICE PLANT.

The ammonia compression plant is essentially the same as that adapted to refrigeration in general. This part of the plant occupies the first and fourth floors. The compressed gas rises to the gas and oil cooler or forecooler, the oil is retained in the oil separator or pressure tank, and the gas, after being liquefied in the condenser, descends to the first floor, where the separating tank is placed, which is intended to trap any oil remaining in the liquid. The liquid is fed as required from this tank into the coils of the freezing tank, from which it passes again in the form of gas to the compressor.

To follow now the water from the well to the loading platform, where it is delivered as ice, we begin with the well-water pump in the boiler house. See Fig. 98. The water from this pump splits into two currents, one of which rises to the top of


AMMONIA CONDENSER
ER.
STEAM FILTER
PRESSURE RELIEF VALVE.
FEED WATER COLLECTOR
LIVE STEAM.
LOADING PLATFORM.
SAND FILTER.
WELL WATER PUMP
BOILER FEED PUMP
BOILERS.
EXHAUST.
FROM WELL.

(To face p. 212.)

the building and discharges into the water storage tank. This water, as shown by the pipes leading from the tank, flows over the gas and oil cooler and also over the ammonia condenser. From the pans or cemented floor on which these stand, it flows to the floor below, where it enters the steam condenser. After traversing the condenser it passes through the next floor, runs along the ceiling, and empties into the vertical stand-pipe (seen to the extreme left) connecting with the sewer. Water from the water storage also flows by a pipe (hidden by the ammonia condenser) to the condensed water cooler, from the base of which it passes through the floor, runs along the ceiling of the first floor, and empties into the sewer stand-pipe.

This disposes of one current from the well-water pump. The other passes through the sand filter whence it rises to the third floor and passes through the heater. From this heater it again descends to the feed-water collector in the boiler-house, whence it is drawn off by the boiler feed-pump, and by it sent into the boilers. It leaves the boilers in the form of live steam. The pipe conveying this live steam has branches supplying the engine, the well-water pump, the boiler feed-pump, and is continued along the ceiling of the first floor, rising to the third floor, where it is connected with the reboiler and also with the steam filter.

The purpose of its connection with the reboiler is apparent. The connection with the steam filter is utilized to automatically supply a small quantity of live steam to make up for any deficiency in exhaust steam. Other connections of the live steam pipe to the various apparatus are shown, which are used for cleaning out.

The exhaust steam from the engine, and also from the two water pumps, passes beneath the first floor and rises through the boiler room and outside the main building to the third floor. Before it enters this it has a chance to escape through the pressure relief valve, if for any reason the various apparatus through which it passes should cause sufficient back pressure to impair the proper working of the engine.

The exhaust steam passes first into the steam filter, thence

to the heater, where it heats the water which, as we have already seen, passes through this same heater on its way to the boiler. From the heater it passes to the condenser, thence to the re-boiler. From this it goes through the condensed water cooler to the deodorizer on its way to the cold storage tank. The names of these various pieces indicate their functions, and need no description.

From the cold storage tank it is fed by a hose to any can put in a place rendered vacant by the withdrawal of a can of ice. There we must leave the now thoroughly purified and distilled water in repose for some sixty hours. After this interval of time, the can is lifted by the ice crane, suspended from the carriage of which it is run down the tank room to the sprinkler. In the sprinkler the can is left to take care of itself. Here it receives a shower bath of warm water and when loosened the ice drops out of itself and glides into the ice storage room, the sprinkler in the meantime automatically putting itself into position to receive another can, thereby shutting off the supply of warm water.

The cake of transparent ice is allowed to remain in the ice storage room until the time for the wagons to appear at the loading platform approaches, when it and as many of its fellow blocks as are required are withdrawn into the ante-room. A block of ice may pass straight through the ice storage room and the ante-room to the loading platform, or it may remain a week or two in the storage. The ice storage room is seen to be supplied with refrigerating pipes so that if the demand is fluctuating the blocks will be preserved intact, only so much being withdrawn into the ante-room as is necessary for immediate use.

STANDARD ICE CANS OR MOULDS.

Weight of blocks.	Size of Can.	Time of Freezing.
50 lbs.	6″ x 12″ x 26″	20 hours.
100 "	8″ x 16″ x 32″	36 "
150 "	8″ x 16″ x 42″	36 "
200 "	11″ x 22″ x 32″	60 "
300 "	11″ x 22″ x 44″	60 "
400 "	11″ x 22″ x 57″	60 "

The time of freezing is with 18° brine.

CHAPTER III.

THE AMMONIA COMPRESSION SYSTEM.

FEATHERSTONE FOUNDRY AND MACHINE CO.

As the successor to several manufacturers of refrigerating machinery, the above-mentioned firm is in a position to offer considerable variety in this line. The list includes single-acting machines, double-acting machines, and even absorption machines. Claiming to own a full line of patents for the last mentioned class of machines, it declines to build any.

The single-acting machine, known as the *Consolidated Machine*, has been on the market for twenty-five years.

The manufacture of the double-acting machine known for years as the *Empire*, has been discontinued recently in favor of the more modern and up-to-date *Featherstone Horizontal Double-acting Machine.*

BRINE SYSTEM AND DIRECT EXPANSION.

While ready to supply either system as demanded, the brine system finds in the people we are considering a faithful advocate. On account of their faith and frankness in this direction, we will quote from their own words:

"We wish to preface our remarks in this connection with the announcement that we are fully prepared to put in either the brine circulation system or the direct expansion system with our refrigerating machines, although we believe the brine circulation system as applied by us to be the most desirable system to adopt, for the following reasons:

"1. With direct expansion, the rupture or breaking of a pipe or connection in any part of the system is almost certain to result in the loss of innocent life, and is equally certain to result in the loss of the whole or greater portion of the charge

of ammonia, which, with the direct expansion system, is necessarily very large.

"2. With direct expansion it is impossible to shut down the machine, even for the purpose of keying up or making any necessary adjustment of connections about the working parts of the machine, without having the piping in the rooms commence to drip as soon as the machine stops, and if for any reason the machine has to be shut down for a number of hours, the temperature in the rooms rises very rapidly, while with brine circulation, and with extra large brine tanks, such as we furnish with our machines, it is possible to stop the machine for ten or twenty hours, or even much longer if necessary, without much, if any, change in the temperature of the rooms, as the brine pump is simply kept at work circulating the great volume of cold brine in the tank through the rooms, keeping them cool until the machine is again started.

"3. In many cases our machines operated on the brine system perform the full work required of them in from eight to fifteen hours per day, and are shut down the balance of the time, thus making a corresponding saving in labor as well as fuel and water consumption; while no matter how much surplus capacity there may be in a machine working on a direct expansion system, the machine must be kept compressing gas continuously every hour of the twenty-four, or the pipes will drip, and the temperature in the rooms will rise rapidly.

"4. With our brine system the whole ammonia portion of the plant is under the eye of the engineer while attending to his duties about the machine, while with direct expansion, the engineer's close attention is required in every room where the ammonia is expanding in the pipes, to keep the expansion valves properly regulated."

VERTICAL COMPRESSOR.

The *Consolidated machine* is built with two single-acting vertical compressors and horizontal engine.

The engine is connected to a crank in the center of shaft. On either side of the crank there are large journal bearings.

The power thus transmitted to the shaft is balanced by two fly wheels, which are turned true and of sufficient weight to cause engine to pass smoothly over maximum point of compression. The power thus balanced is delivered to the pumps or compressors.

The advantage of connecting the engine to a crank in the center of the shaft and of placing a fly wheel between the engine crank and each pump crank (instead of placing the pump crank between the engine crank and fly wheels, or connecting the engine to one end of the shaft and to the same crank pin with one of the pumps), lies in the uniformity and steadiness of motion secured and in the diminished tortional strain, vibration and friction of the crank shaft.

The pump columns are very heavy, terminating at the bottom in broad flanges which are bolted to massive foundation plates. These columns are cast in one piece, forming a strong frame. The foundation plate is provided with four large journal bearings for crank shaft.

The compressors, as stated, are set vertically, and are single-acting, compressing only on the up stroke. The evaporated gas has free entrance to and exit from the cylinder below the piston, thus keeping the pump cylinder and piston cool. The extreme lower portion of the pump forms an oil chamber or reservoir, which effectually seals the stuffing-box around the pump piston-rod, and as the pressure on the stuffing-box end of the pump is only the direct evaporator pressure, about one-eighth of the condensing pressure usually, there is practically no chance for the escape of ammonia through the stuffing-box.

The suction and discharge valves are located in the pump head. The suction valve is balanced, allowing the pump to fill freely with expanded gas from the evaporator. The discharge valves, of which there are two, have ample area for discharging the compressed gas, and are so cushioned as to be noiseless in their operation. The valves are set in steel cages, which are held in position in the pump-heads by means of yokes and set-screws, so that the work of removing the valves whenever it is desired to do so, may be accomplished in a

moment, and a duplicate valve can as quickly be put in place, and the machine started up immediately.

The suction and discharge pipe connections are made outside of the pump-head, so that when for any reason it is desired to remove a pump-head, neither of these connections needs to be disturbed.

The piston when packed is practically solid, and is adjusted to run practically flush with the pump-head.

The stuffing-box is operated by a worm gear, so that the simple turning of a hand-wheel adjusts the same while the machine is in motion.

The upper portion of the machine is surrounded by a copper water-jacket. The pumps are lubricated by a sight-feed oiling system which automatically feeds the oil required for the lubrication of the pumps with the economy and exactness of a sight-feed steam engine lubricator.

HORIZONTAL COMPRESSOR.

The *Featherstone machine* is built with horizontal engine and horizontal double-acting compressor. The crank shaft is straight and very heavy, with a fly wheel placed in the center between the two main bearings. These compressors are all built on the heavy-duty Tangye frame, which has been recognized as being the most substantial design for machines of this type.

A view of complete machine is shown in Fig. 67, and a sectional view of compressor cylinder in Fig. 99.

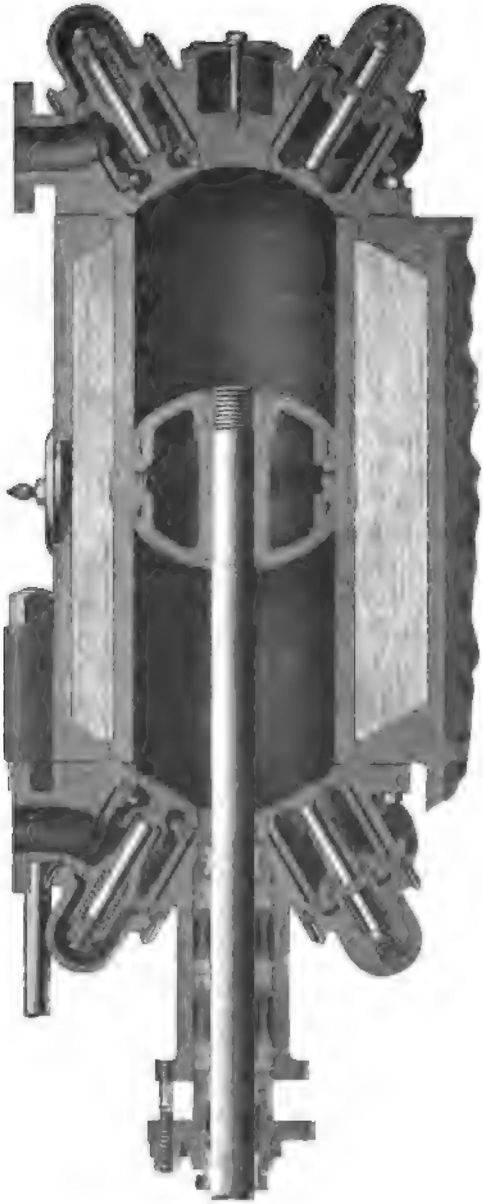
The advantage of being able to quickly remove and replace both sets of suction and discharge valves is attained in horizontal machines as with Consolidated machines.

The discharge valves are located at the lowest point of the cylinder.

Special by-pass connections are furnished so that the ammonia can be drawn from one part of the system to another.

The pump cylinder is provided with a water jacket for cooling, and the compressor may, therefore, be operated either as a dry gas machine or as a humid gas machine.

FIG. 99.



SECTIONAL VIEW OF FEATHERSTONE DOUBLE-ACTING AMMONIA COMPRESSOR.

The crosshead guides and the cylinder are bored out at the same time, and are, therefore, relatively true. The crosshead has babbitted gibbs and wedge adjustment. The piston rod is screwed into the crosshead and properly secured by a jam nut so that the clearance, which is reduced to a minimum, may be easily adjusted. The connecting rod is of the marine type and of hammered steel.

The stuffing-boxes are oil-sealed. The oil leakage from the stuffing-box to the cylinder is designed to provide proper lubrication of the latter.

These machines are so constructed that they can be attached to any steam engine or operated by a belt.

CONDENSERS.

The standard ammonia condensers are constructed of two-inch pipe made from skelp selected especially for ammonia use. The pipes are connected by semi-steel return bends, a tight joint being insured by the use of a Boyle gasket. When the condenser consists of more than one section, each section is provided with stop valve on inlet and outlet, so that any one or more sections can be shut off without interfering with the operation of the remaining sections. An auxiliary header is also provided, having stop valve on each section and connected with the suction of the machine so that when desired the ammonia may be drawn out of any one or more sections. The condensers are tested to 500 pounds air pressure before being shipped. Where circumstances prevent the installing of atmospheric condensers, either submerged or double-pipe condensers may be used.

AMMONIA RECEIVERS.

Ammonia receivers are of very heavy pattern, furnished with glass gauges, shut-off valves, and with inlet and outlet valves and draw-off valves for the ammonia. The gauge valves are of the needle-point pattern, and so arranged that they close automatically, should the gauge glass become broken.

COILS, PIPES AND CONNECTIONS.

The coils for both condensing and evaporating surfaces are made from extra-strong pipe of special quality. They are made up without return bends, being bent and welded by a special process, being without a connection from end to end. Bends are made without flattening, the iron at the outer circumference of the bend not being drawn and weakened, but the iron on the inner circumference is upset, making this portion of the pipe thicker.

Ammonia valves are of special design. They are provided with soft metal seats. All are tested under an air pressure of five hundred pounds per square inch.

Ammonia unions are of the "Boyle" type. With these unions the pipe is screwed into the flange and the joint made by compressing rubber rings around the pipe and ferrule ends by the tightening of the bolts. Similar joints are made with the other flange fittings, as shown in Figs. 43 to 49 inclusive.

TESTS.

The summary of the results of a test of a fifty-ton refrigerating machine are given below. This shows that there was developed a duty equivalent to the melting of 78.41 tons of ice in twenty-four consecutive hours, with a coal consumption of 6,108 pounds, and a water consumption of 21.19 gallons per minute. The brine system was used, there being two brine tanks. The test extended over twenty-four hours. The boiler used was of the double-deck type, of the following dimensions:

Diameter—Five feet (5′).
Length—Sixteen feet (16′).
Number of tubes—Seventy-three (73).
Diameter of tubes—Four inches (4″).
Diameter of Drum—Four feet (4′).
Length of Drum—Eighteen feet (18′).
Width of Grate—Five feet (5′).
Length of grate—Five feet six inch (5′6″).

The following are the results of the observations, viz.:

Engine, vertical direct-acting, with Corliss valve gear.
Cylinder 18″ x 36″. Compressors 12⅜″ x 30″, single-acting.

Average steam pressure	86 lbs.
" revolutions per minute	56.5.
" indicated horse-power of steam cylinder	84.3.
" " " " compressors	67.78.
" temperature of condenser room	62.5 deg.
" " condensing water	76.2 deg.
" quantity of condensing water per minute	21.19 gal.
" difference in temperature of brine	8.96 deg.
" evaporating pressure	25.22 lbs.
" condensing pressure	157.12 lbs.
Total amount of brine metered	35,670 cu. ft.
Weight per cu. ft. of brine established	70 lbs.
Total number of lbs. of brine	2,496,900 lbs.
Total units of heat at 142.65 lb.	22,372,204 lbs.
Capacity in tons of ice melted in twenty-four consecutive hours	78.41 tons.

BOILER.

Kind of coal, anthracite, chestnut.

Lbs. of coal consumed	6,108
" " " per hour	254.5
" ashes	1,000
" combustible	5,108
Percentage of ashes	16.37 %.
" " combustible	83.63 %.
Lbs. of coal per indicated horse-power per hour	3.02 lbs.
" combustible " " " "	2.52 lbs.
Average temperature feed-water entering boiler	190 deg.
Coal consumption for refrigerating duty equivalent to the melting of one ton of ice	77.88 lbs.

ICE-MAKING.

In the first ice-making plants by these people the ice was made from undistilled water frozen on plate. While these machines were successful and proved satisfactory at the time, present methods result in improvement in point of economy and quality of ice produced. These methods involve the use of distilled water, utilizing the condensed steam from the engine, which is purified, condensed, filtered and cooled to a low temperature before it is delivered to the moulds where it is frozen.

Nearly all the machines originally using the plate system have been changed over to the distilled water system.

In place of a large, deep brine tank used as for refrigerating, a more broad and shallow tank is used for ice-making, in which tank the moulds or cans with the distilled water to be frozen are placed. The brine is kept in motion around the cans by a circulating pump.

A table is found on page 224, showing the size of ice-making machines, with data in regard to same. With this table as a basis, the expense of running a machine can be readily estimated.

TABLE FOR ICE-MAKING PLANTS.

Ice-Making Capacity in 24 hours.	Style of Engine.	Size of Ice, Inches.	Fuel.	Water per minute.	Engineers.	Firemen.	Laborers.	Approximate Shipping Weight.
1 Ton	Slide valve	8 x 8 x 28	½ Ton Coal.	5 Galls.	2	2	. . . . .	20,000 lbs.
3 "	Slide valve	8 x 15 x 28	1 " "	15 "	2	2	2	58,000 "
5 "	Adjustable cut-off slide valve	8 x 15 x 28	1½ " "	20 "	2	2	2	69,000 "
10 "	Corliss or Adjustable cut-off slide valve	11 x 22 x 28 11 x 11 x 28	2 " "	30 "	2	2	3	101,000 "
12½ "	Corliss or Adjustable cut-off slide valve	11 x 22 x 28 11 x 11 x 28	2½ " "	35 "	2	2	3	129,000 "
15 "	Corliss or Adjustable cut-off slide-valve	11 x 22 x 28 11 x 11 x 28	3 " "	40 "	2	2	4	167,000 "
20 "	Corliss	11 x 22 x 28 11 x 11 x 28	4 " "	50 "	2	2	5	190,000 "
30 "	Corliss	11 x 22 x 28 11 x 11 x 28	5 " "	60 "	2	3	6	225,000 "
40 "	Corliss	11 x 22 x 28	6½ " "	90 "	2	4	7	260,000 "
80 "	Corliss	11 x 22 x 28	13 " "	160 "	3	6	10	360,000 "

CHAPTER IV.

THE AMMONIA COMPRESSION SYSTEM.

THE PENNSYLVANIA IRON WORKS CO.

IN 1892 the Pennsylvania Iron Works Co. entered into an agreement with the estate of the late David Boyle, a pioneer in refrigerating work, whereby it assumed right and title to the patents granted him for improvements in ice-making and refrigerating machinery. Accordingly, the company launched out into the field of artificial refrigeration and ice-making, equipped with an established, complete and effective system. Improvements in details demonstrate that the system has not suffered in the hands of its new owners. The company has to its credit the construction of a machine that for years held the record as the largest refrigerating machine yet constructed. The machine referred to was built for The Quincy Market Cold Storage Company, of Boston. Its completion was followed by an order for a duplicate.

This machine, shown in Frontispiece, has two single-acting compressors 26 inches in diameter and with 48 inches stroke. It is run by a compound tandem condensing engine with steam cylinders 24 inches and 44 inches in diameter and 60 inches stroke, height above capstone 24 feet, length over all 45 feet, width 20 feet, and weight 200 tons. There are two fly wheels 16 feet in diameter, and weighing 30,000 pounds each. The main crank shaft is 16 inches in diameter. There are iron platforms around the compressor cylinders, both at top and bottom and at each cross-head.

The condenser contains 15,500 feet of 2-inch kalamined pipe, made in 31 coils, placed in two stories, there being 17 coils in the lower section and 14 coils in the upper. These

coils are 27½ inches on centers, with ample room between for cleaning.

The machine that has been thus briefly described is of the general type, as shown in diagram, Fig. 100. The compressors are of the vertical, single-acting type, the compression taking place in the upper part of the cylinder.

Fig. 100.

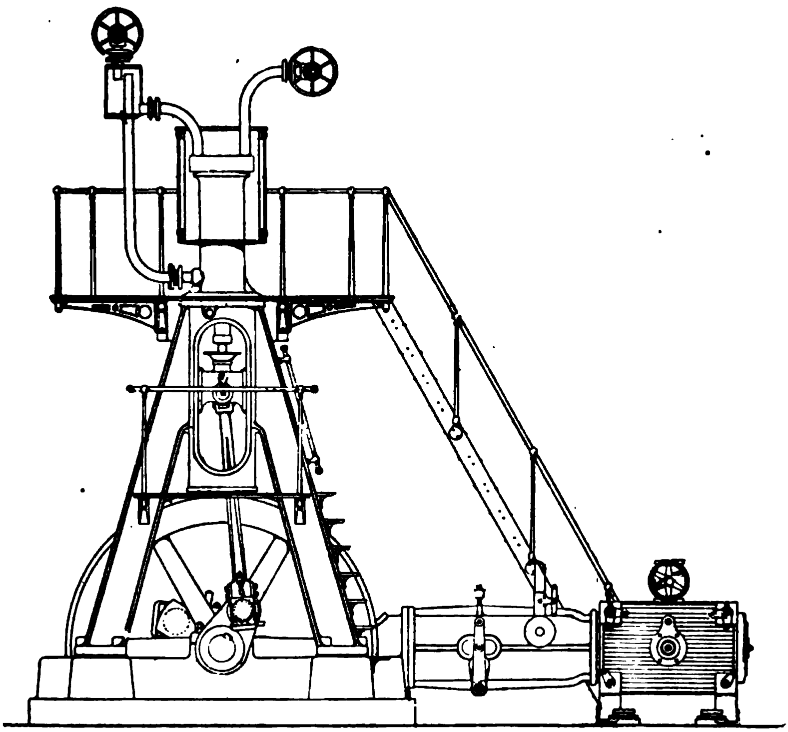
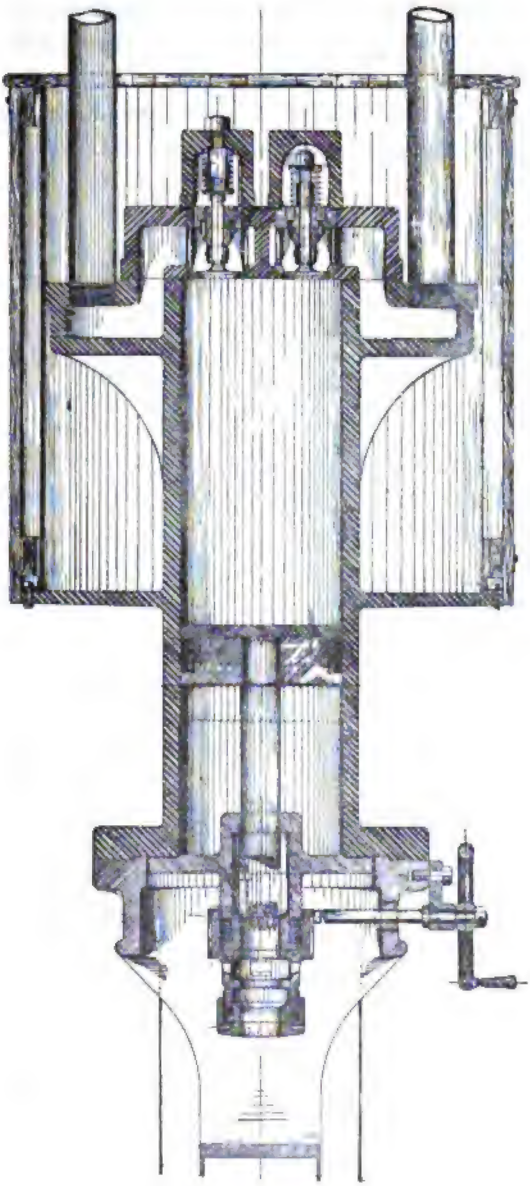


DIAGRAM OF COMPRESSOR AND ENGINE.
Pennsylvania Iron Works.

The engines are generally of horizontal type. In special cases, as especially in marine work, vertical engines are used.

For the purpose of cooling the cylinder, the expanded gas from the refrigerating coils is admitted to the lower portion of the cylinder, and a water-jacket is provided around the upper portion.

FIG. 101.

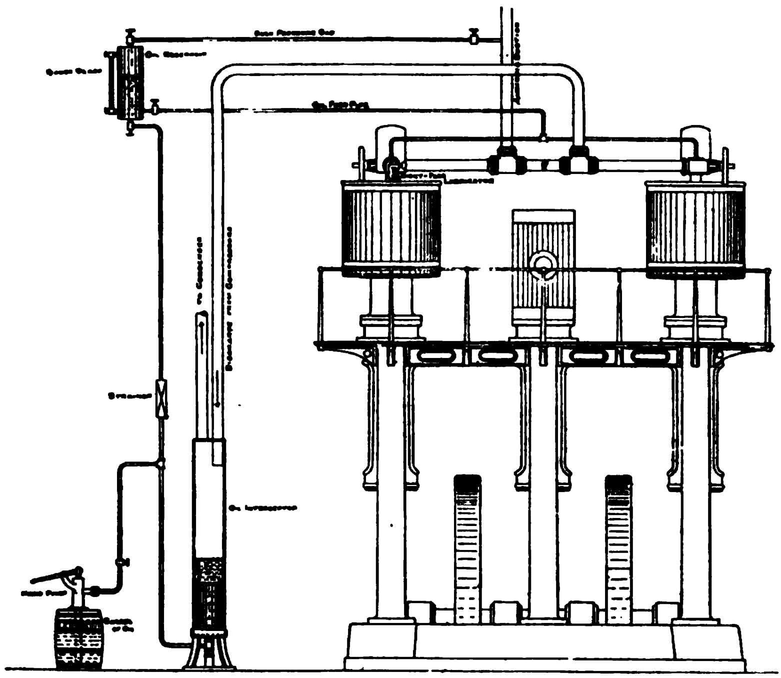


BOYLE PATENT AMMONIA COMPRESSOR.

Sectional view of compressor cylinder, water-jacket, valves and stuffing-box.

Fig. 101 shows a sectional view of the compressor cylinder, water-jacket, valves and stuffing-box. The compressor valves, which are spring valves, are located at the upper head of the cylinder. The valves are shown in place in the view of the section of the cylinder, Fig. 101. The general plan of the suction and the exhaust valves may be obtained from the

FIG. 102.



LUBRICATOR DEVICE FOR COMPRESSOR.

views, plan and elevation (in section) of the suction valve shown in Fig. 79.

COMPRESSOR LUBRICATING SYSTEM.

A special lubricator system employed on the compressors is of interest. The arrangement of the same is shown in Fig. 102. The compressor is provided with a sight-feed lubricator fed from an oil reservoir located at some convenient point

above the machine. The reservoir is provided with a gauge glass with the usual shut-off cocks for determining the amount of oil in the same. From any point on the suction side of the machine a connection is made with the top of the oil reservoir, giving a pressure to the amount of the back pressure above the oil. This pressure insures the feed of the oil from the lower part of the reservoir through a conducting pipe to the compressor.

The oil thus fed into the compressors is discharged in the form of vapor with the ammonia gas into an oil intercepter, in which the oil is separated from the ammonia, the oil being deposited at the bottom while the dry gas passes from the top to the condenser.

By opening the valve in the bottom of the oil intercepter the accumulated oil is driven upward into the oil reservoir, to be used again, the supply only being replenished from time to time from an oil tank or barrel, to which is attached a small force-pump for the purpose.

An oil strainer is located in the connecting pipe to remove any dirt or grit that may be in the oil.

The device combines convenience, cleanliness and economy of oil; all necessity of opening any part of the system to the air for the purpose of attending to or adjusting the lubrication of the cylinder being entirely avoided.

BOYLE PATENT ATTEMPERATOR.

The Boyle patent attemperator has already been shown in Figs. 16, 17, and 18. This is arranged with a swivel joint, so that it can be swung up out of the way. Fig. 16 shows the swivel joint, Fig. 17 the attemperator in place, with section of tank removed, while Fig. 18 shows a plain view.

ATMOSPHERIC AMMONIA CONDENSER.

A view of the atmospheric condenser complete, including the tank for catching the water that flows down from the section of pipe, is shown in Fig. 103.

FIG. 103.

IMPROVED ATMOSPHERIC AMMONIA CONDENSER.

CHAPTER V.

THE AMMONIA COMPRESSION SYSTEM.

ECLIPSE REFRIGERATING AND ICE-MAKING MACHINERY.

THE characteristic features of a compression system of refrigeration may be looked for in the compressor. These include the class of pump, the method of coupling the same to the motive power, and the details of the compressor cylinder and piston.

THE TYPE OF MACHINES.

The Eclipse machines consist of a pair of single-acting vertical compressor pumps driven by a horizontal steam engine, all forming one structure.

Other special features are the use of a safety head at the upper end of the compressor cylinder and the location of the suction valve in the compressor piston.

The usual claims for the advantage of single-acting machines are advanced, a few of which it may be instructive to consider.

SINGLE-ACTING VERSUS DOUBLE-ACTING PUMPS.

Vertical pumps are not subject to bottom wear of the pistons, as is the case with horizontal pumps, where the weight of the piston is necessarily supported by the cylinder bore, producing needless friction, with a strong tendency to wear the cylinder oval, and more particularly the narrow surface of the piston, to such an extent that leakage of gas occurs past the top of same. Part of the weight of the piston is also taken by the piston rod when near front end of cylinder and rests on the stuffing-box, which makes it rather difficult to maintain the piston rod packing.

BALANCED FORCES, SINGLE-ACTING MACHINES.

In the vertical pattern the pump cranks are placed opposite each other and the forces are balanced. The wear of the pump cylinder bore and piston rod, owing to their vertical position, is uniform and very slight, and the saving in friction a considerable item. There are other advantages, such as economy of space, use of a large vertical water-jacket, separation of dirt, ease of lubrication, etc.

FREEDOM FROM LEAKAGE, SINGLE-ACTING.

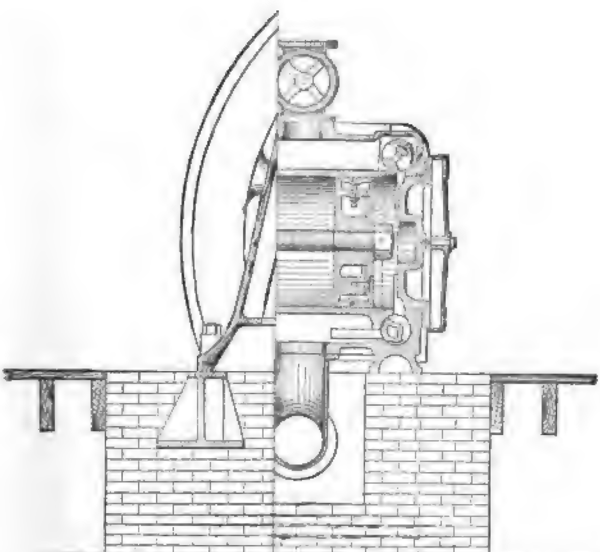
The single-acting pump compresses the gas on its upward stroke, hence the condensing pressure comes only above the piston. This pressure ranges from 125 pounds upward per square inch, the space below the piston being subjected only to the low suction pressure of gas ranging from 0 to 35 pounds, hence in the single-acting machine the stuffing-box packing is more easily kept tight without undue wear and friction of the piston rod than in the double-acting pump, which, having to compress gas on the lower stroke to condensing pressure, necessitates a tight stuffing-box, which causes undue friction, heating and wear of piston rod.

In the single-acting pump, because of the low pressure on the piston packing box, the leakage of ammonia past the piston rod is easily prevented. This in itself is an important saving.

STANDARD COMPRESSOR.

Fig. 104 is a sectional view of a standard machine complete with engine and foundation, and Fig. 105 a sectional view of the cylinder of the compressor, showing details of the cylinder, piston, valves, water-jacket, stuffing-box and packing, the method of lubricating by means of hand oil pump, and the means of adjustment by bevel gears, the projecting shaft having square head for wrench.

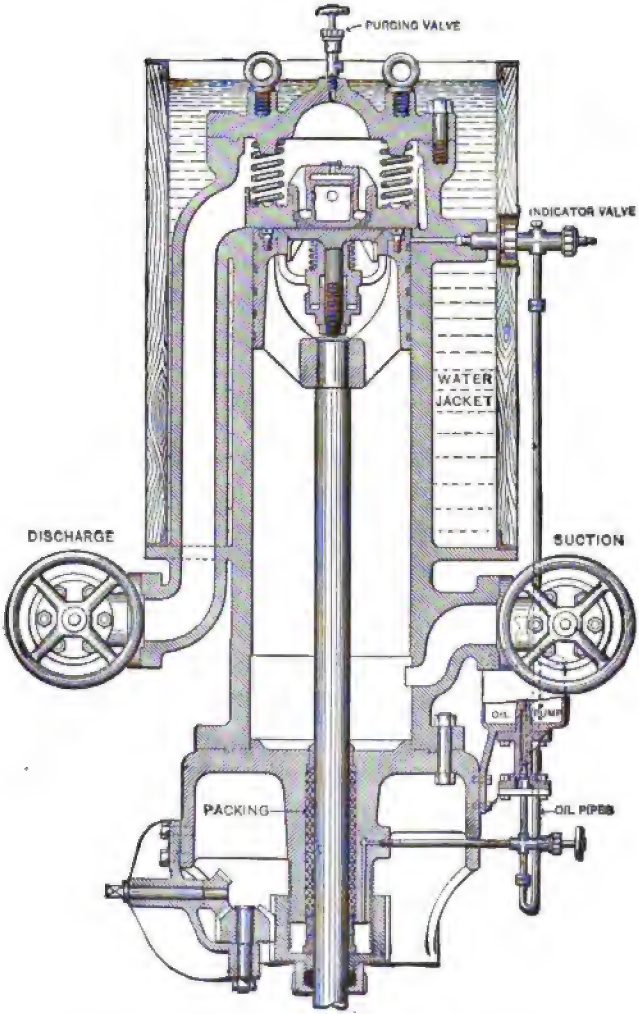
A prominent and striking feature of the design is the employment of rectangular tapering box girder columns for supporting the pumps, forming a solid, rigid foundation for main bearings. The bottom ends of the columns terminate in a



SECT SYSTEM. (Opposite p. 232.)

broad base or flange, which is bolted to heavy foundation base plates. The upper works are provided with a gallery and

FIG. 105.



SECTION "ECLIPSE" COMPRESSOR CYLINDER.

convenient stairways. On the larger machines an upper and lower platform are furnished. The fly-wheel is located be-

tween the pumps. The connecting rod of the horizontal engine acts directly upon the main crank. Altogether the design is novel and pleasing, and strikes the observer as being a splendid adaptation for the purpose to which the machine is applied.

WATER-JACKET.

The gas parts with more or less of the heat of compression through the wall of the cylinder, the dome and cylinder being enveloped in a water-jacket, through which the cold water is constantly circulating. This jacket not only tends to prevent superheating of the gas during compression, but likewise tends to materially assist the condenser and cut down to a marked degree the gas resistances that would present themselves without its use.

SUCTION VALVE.

The steel suction valve, of large area, is situated in the piston, the gas inlet being in the base of the pump. The suction valve being balanced by a spring, offers upon the return stroke of the piston no resistence to the gas, which flows, under the back pressure, with considerable velocity into the vacant space above the piston. A cushion and spring assist in closing the suction valve promptly and noiselessly as the up stroke is begun, the imprisoned gas being gradually compressed until it equals the condensing pressure acting upon the discharge valves, located in the pump dome, when the discharge begins.

THE SAFETY COMPRESSOR HEAD.

In order to make it perfectly safe to work the piston metal to metal against the top cylinder head, the better to expel the full charge without danger, the pump-head is made movable, or is what may be called a safety head. In other words, it is simply a large valve the full size of bore of pump, through the seat of which the piston may pass without injury, raising the head before it sufficient, in case of any part getting loose, that no damage can ensue, such as knocking out a cylinder

head, thus losing the full charge of ammonia gas and endangering life.

THE DISCHARGE VALVE.

The safety head does not work as a valve, the real operating discharge valve being the steel valve in the centre of the same. The safety head with its discharge valve, guides and seat are self-contained and independent of the pump cylinder, making it convenient to replace the whole valve mechanism by a duplicate one or make speedy repairs.

INDICATOR VALVE.

The small valve at the upper right-hand corner of cylinder, Fig. 105, is for taking indicator diagrams from the pump, and to inject oil in that portion of the cylinder, if any be needed, when starting up a new machine or when testing under air pressure.

EASE OF ACCESS TO PUMP MECHANISM.

A novel feature is that all parts of the pump mechanism are easy of access. By simply removing the dome-head the valves are exposed to view for examination or adjustment, and the entire valve mechanism can be removed in a twinkling.

"BYE PASS" ON GAS PUMP.

There is provided a "bye pass," located on the pump platforms, enabling the engineer to exhaust the ammonia from any part of the system (stop-valves being furnished to isolate every part), and store the ammonia in any other part temporarily until the repairs or examinations are made.

The "bye pass" is also used for exhausting the pumps themselves before the heads are taken off for examination. By means of its peculiar arrangement of pipes and valves, it is possible to reverse the action of the pumps and exhaust the ammonia from the condenser, storing it in the expansion coils.

In each case, after the examination of any part, the air can be exhausted therefrom and charge of ammonia re-introduced without the admixture of air.

AMMONIA CONDENSERS.

THE SUBMERGED CONDENSER is built after the general plan shown in the brine tank (Fig. 6, Part I). The ammonia gas from the compressor is passed through the pipe coils, arranged in multiple. These pipes are surrounded by cold water.

In this apparatus the arrangement followed is for the water to be admitted at the bottom and to be drawn off at the top, and the incoming gas to be admitted at the top and drawn off at the bottom. By this arrangement the hot gas will be first brought in contact, so to speak, with the warmer water at the top, and as it becomes cooler and passes down it will be acted upon by the colder water, and consequently the best results possible will be thus obtained.

THE ATMOSPHERIC CONDENSER is built up of sections. Each section is provided with the proper inlet and outlet valves, so that each is independent, and may be cut out for repairs without interfering with the others. The water is fed along the entire length from a pipe at the top, drips down over the pipes below in succession, and is then caught in a pan at the bottom. This water is not led off to the sewer, as is done in some cases, but is conducted to the distiller. Water from the distiller over-flow is pumped into the boiler. In Fig. 33, Part I, is shown an atmospheric condenser with double-pipe liquid fore-cooler.

DESCRIPTION OF BRINE TANK.

In Fig. 6 is shown a section of a circular tank with circular coils. The tank is built with thick walls, set upon a foundation of brick or concrete, and is provided with a thick wooden cover. The insulation usually is made up of granulated cork, several thicknesses of boards, with P. & B. paper between, and one or two air spaces.

The coils are arranged in multiple. In the case shown there are four coils connected at one end to one header, the other ends being independent, and provided with valves, thus permitting of the proper regulation of the individual coils. As the inner coils have a shorter circumference than the outer

coils, these coils are given more turns than the outer ones to compensate for this, so that the lengths of the four coils are practically the same. The expansion valve is located at the top of the coil, so connected that the ammonia enters the top of the coil and flows toward the bottom. The brine is drawn off from the lower portion of the tank by the brine circulating pump through the suction pipe indicated, and returned through the pipe entering through the top at the center.

PIPING.

To make the proper allowance and arrangement of the circulating pipes in the rooms to be cooled is an important function of the refrigerating engineer. Of next importance is the quality of the piping and fittings. It is needless to say that only the best of materials should be employed. All this involves special study and the display of good judgment.

In looking over the field there will be noticed the appearance of hobbies and peculiar and conflicting claims. A certain kind of apparatus that is lauded by one is decried by others.

In the Eclipse system special claims are made for valves. Cocks are tabooed. They are set down as barbarous, crude and cheap, and are looked down upon because they were used before valves were invented. Furthermore it is said :

"They are hard to open, stick, and are liable to cut, from dirt working between the surfaces. The expansion and contraction of the barrels of the cocks changes the form, rendering them leaky ; they also leak at each open end, and, when much worn, blow through ; they require a long wrench to move them, and the full strength of a man, sometimes two men, and a sledge. When a cock is to be opened or shut the engineer has to spend time looking around for the wrench handle, which is so awkward and clumsy that it is never left on the cock ready for use.

"That these cocks are treacherous is recognized by one of the principal users of same on ammonia machinery, who takes the precaution to provide and bolt on each side of the cock a

tight flange cover, which is a standing advertisement that cocks are dangerous and require to be boxed up to make them safe; and safe they are, so long as they are not needed for use. But sometimes the engineer wants to get at the cock in an awful hurry, then he has to stop to take off the cap, let the residual ammonia pass off, hunt up his wrench, and by that time he is about dead with the escaping gas. Result, big loss of ammonia.

"With a valve it is different—always ready, large hand-wheel in place, easy to close, easy to open, and in case of accident, safest and most satisfactory of all devices.

"Cocks are a relic of a bygone age, and will not do for modern machinery."

ICE-MAKING MACHINERY.

FREEZING TANK.

The freezing tank is made of steel, and well coated with waterproof paint. Wooden tanks, while much cheaper, are very unsatisfactory, owing to leakage and short time they last.

Fig. 106 is a sectional view of a can freezing tank, and discloses the interior arrangement thereof, showing the arrangement of ammonia evaporating pipes, ice moulds, framework for holding the cans in position with wooden covers and agitator.

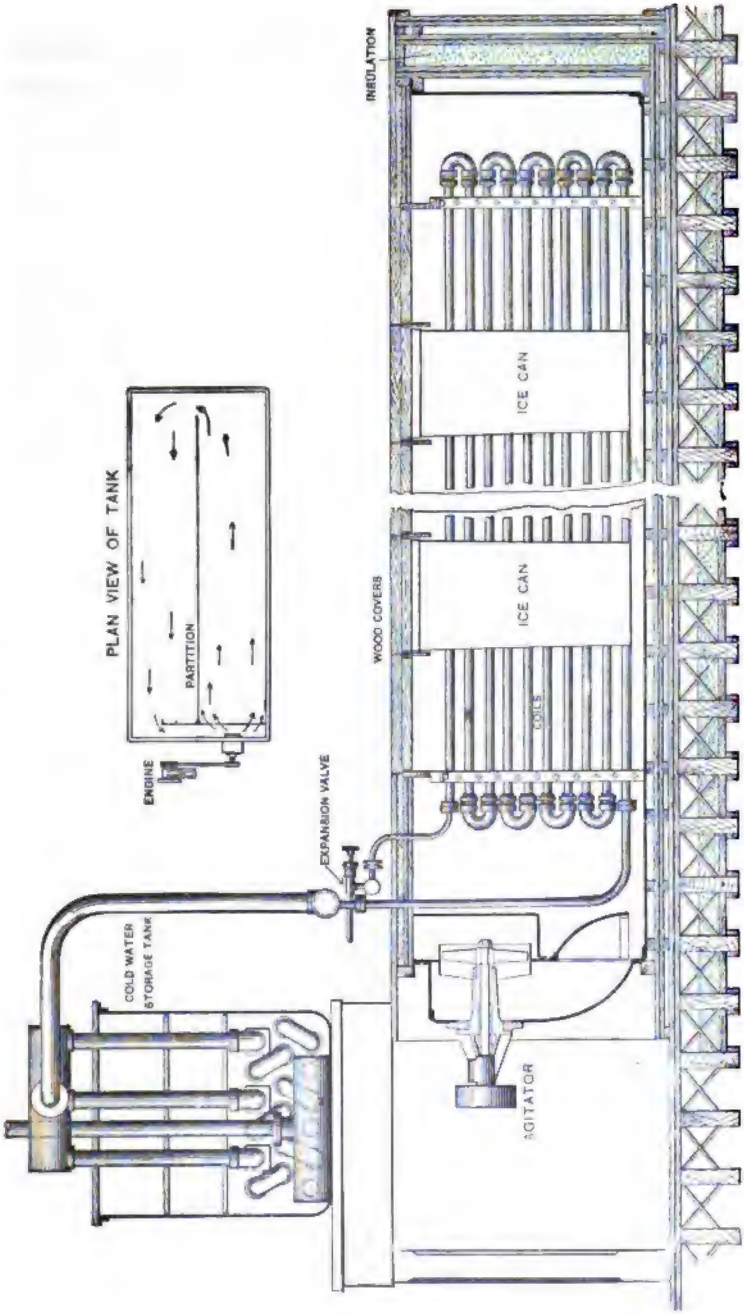
WOODEN COVERS FOR CANS AND GRATING.

The grating or framework to hold cans in tank is made of oak, and covers are thoroughly made of two thicknesses of 2-inch dressed oak. The framework is well jointed and screwed together.

EVAPORATING COILS.

Parallel rows of ammonia pipes with space between each set to admit of a row of moulds are submerged in the brine, with which the tank is filled. The water in being frozen gives up its heat to the brine, which in turn gives up this heat to the expanding ammonia in these ammonia pipes. The contents of the cans are frozen into a solid, sparkling mass of ice in from 22 to 48 hours, depending upon thickness of mould and temperature of brine.

Fig. 106.



DETAIL ARRANGEMENT OF FREEZING TANKS FOR ICE FACTORIES.

SECTION OF "ECLIPSE" ICE TANK.

THE ICE MOULDS.

The ice moulds are of six sizes—50, 100, 150, 200, 300 and 400 pounds. The actual weight of the cake is about 10 per cent. greater, however, to allow for wastage. The demand of the locality influences the selection of the size of cake and determines the weight to be used.

TAKING THE ICE OUT OF THE MOULDS.

A suitable hoisting arrangement, traveling upon iron rails, over each tank, is used for lifting the moulds out of the tanks, and they are then carried by the hoist to a thawing device, which soon loosens the ice from the can. The mould is then tipped over an inclined runway, the cake of ice easily slipping out of the can and sliding down the runway through a trap into the ice-house or ante-room, where it is temporarily stored, awaiting delivery to customers.

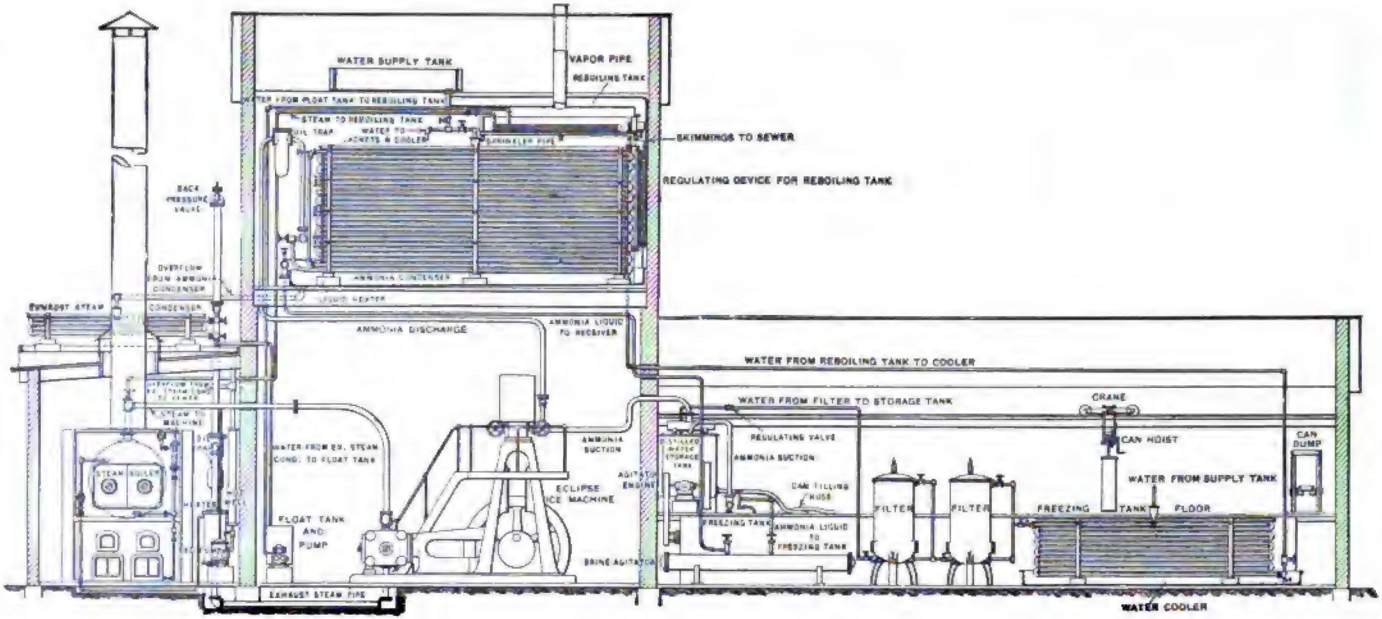
ECONOMY IN USE OF WATER.

In the Eclipse system of making ice the water is greatly economized, as the same water is used first on the ammonia condenser, then again for distilling, then pumped from the distiller overflow into the steam boiler, the steam therefrom being used in the engine, and afterwards condensed in the distiller, and finally, after thorough purification, utilized to fill the ice-moulds, hence the total water supply is reduced to a minimum. See Fig. 107.

WATER DISTILLING SYSTEM.

Exhaust steam from the engine is generally used to supply the distilled water for filling the ice moulds. See Fig. 108. The reason for this is that it is economy to pass the steam through the engine first before distilling, as by this method at least 60 per cent. of the fuel is saved that would be required if steam were taken direct from the boiler for distilling, in addition to requirements of engine; in other words, to use a common phrase, to "take the power out of the steam first." The apparatus used thoroughly separates the oil and impurities

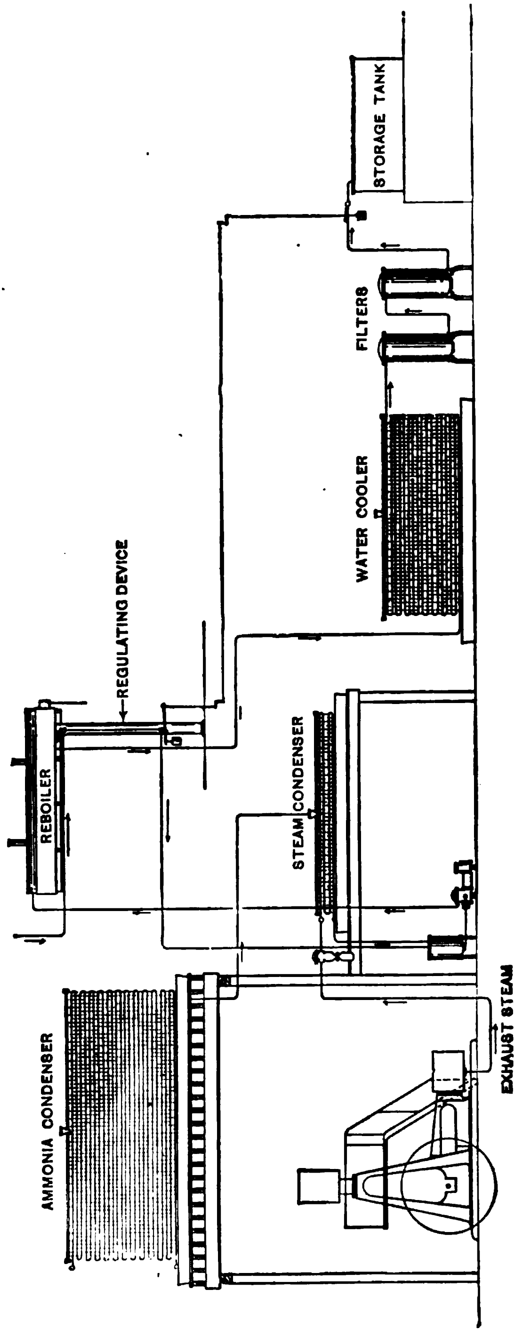
Fig. 107.



IMPROVED "ECLIPSE" ICE FACTORY (SHOWING ARRANGEMENT OF COMPLETE FACTORY).

16

FIG. 108.



IMPROVED "ECLIPSE" DISTILLING SYSTEM.

from the exhaust steam, and permits the use of any mineral oil that is suitable for lubricating the valves and piston of the engine, as with this apparatus the oil is so completely eliminated from the steam that the ice is not affected. In larger plants the exhaust steam from the engine is not sufficient to make up the required quantity of distilled water. The deficiency has to be made up of fresh water, which is either boiled distilled or drawn direct from boiler, undergoing a purifying and cleansing process before it is used in the cans.

WATER-POWER ICE PLANT.

Where water-power can be had, it is recommended to use the "plate system," the water being subjected to a thorough system of filtration, no steam being required. See Fig. 109.

THE "ECLIPSE" PATENT PLATE SYSTEM.

The "Eclipse" patent plate system for making ice is especially adapted where water-power is obtainable, as pure, transparent ice may be made by this method from potable water without being distilled, water being taken from usual sources of supply and, when necessary, thoroughly filtered, and subjected to special treatment if required.

In this system of freezing the cake may be of large size, the standard being 16 feet long, 8 feet wide and 12 inches thick. The impurities are forced out of the water in the process of freezing, and are found as a precipitate at the bottom of the compartment in which the ice is frozen, and which may be thoroughly cleaned out by washing, before fresh supply of water is run in for freezing.

Ice made by the plate system is similar to the best Kennebec ice in grain and texture, but surpasses it in coldness, solidity and transparency, and may be split into convenient sized blocks in the same way as natural ice.

With the larger plants are used power gang-saw cutting rig, with suitable carriages and arrangement of saws that any convenient size may be cut partly by the saws and easily split up into blocks having clean, square corners and with but little waste.

FIG. 109.

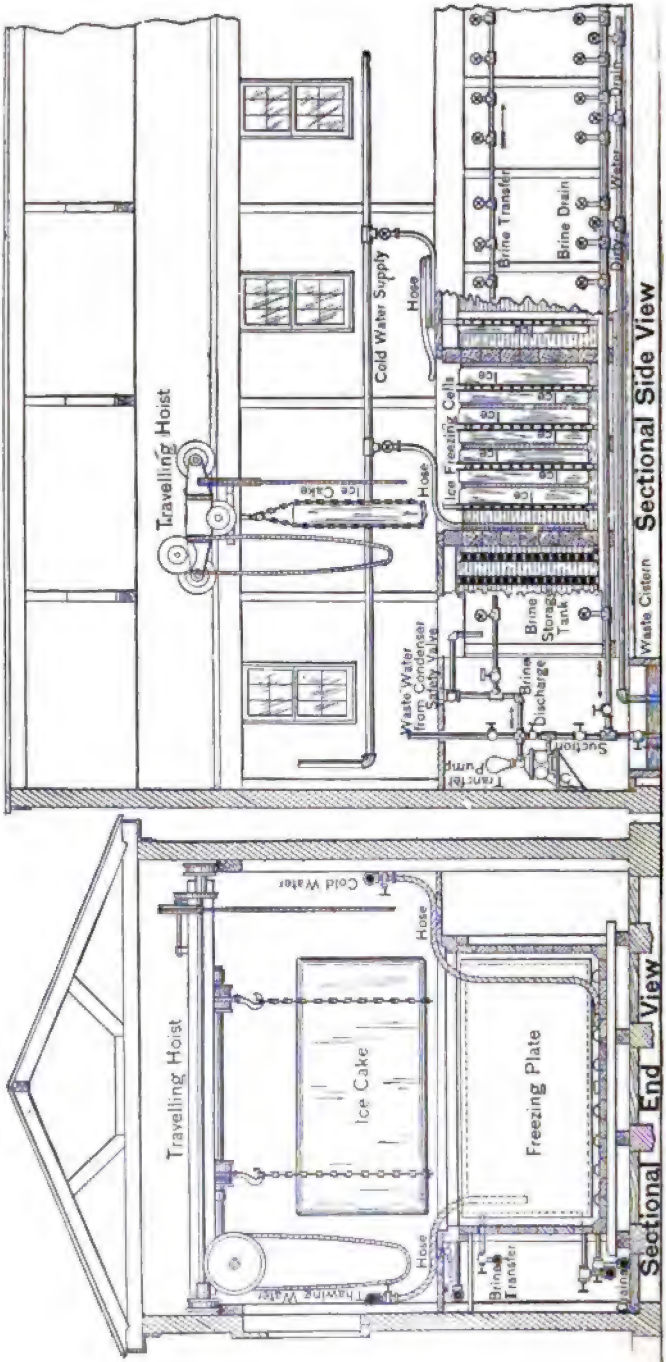


PLATE ICE-MAKING PLANT (ECLIPSE).

Geared traveling cranes, either hand or power, are used to hoist the large plates of ice from the freezing compartments and transport them to the cutting table with surprising ease, certainty and safety, enabling the harvesting of the ice to be done at the minimum labor cost.

Those who have carefully considered the subject of ice-making will see at a glance the application of the system where the locality, conditions and trade requirements give assurance of its commercial success.

CHAPTER VI.

THE AMMONIA COMPRESSION SYSTEM.

THE YORK MACHINE.

The manufacturers of the "York Machine" have had extensive experience in building various types of machines, including double-acting, single-acting, and compound types, both horizontal and vertical. As a result of this experience they have adopted as their standard type of machine the vertical machine, single-acting, with false head to the cylinder, combined with a horizontal engine, notwithstanding the fact that this style of machine is comparatively expensive to build.

THE COMPRESSOR.

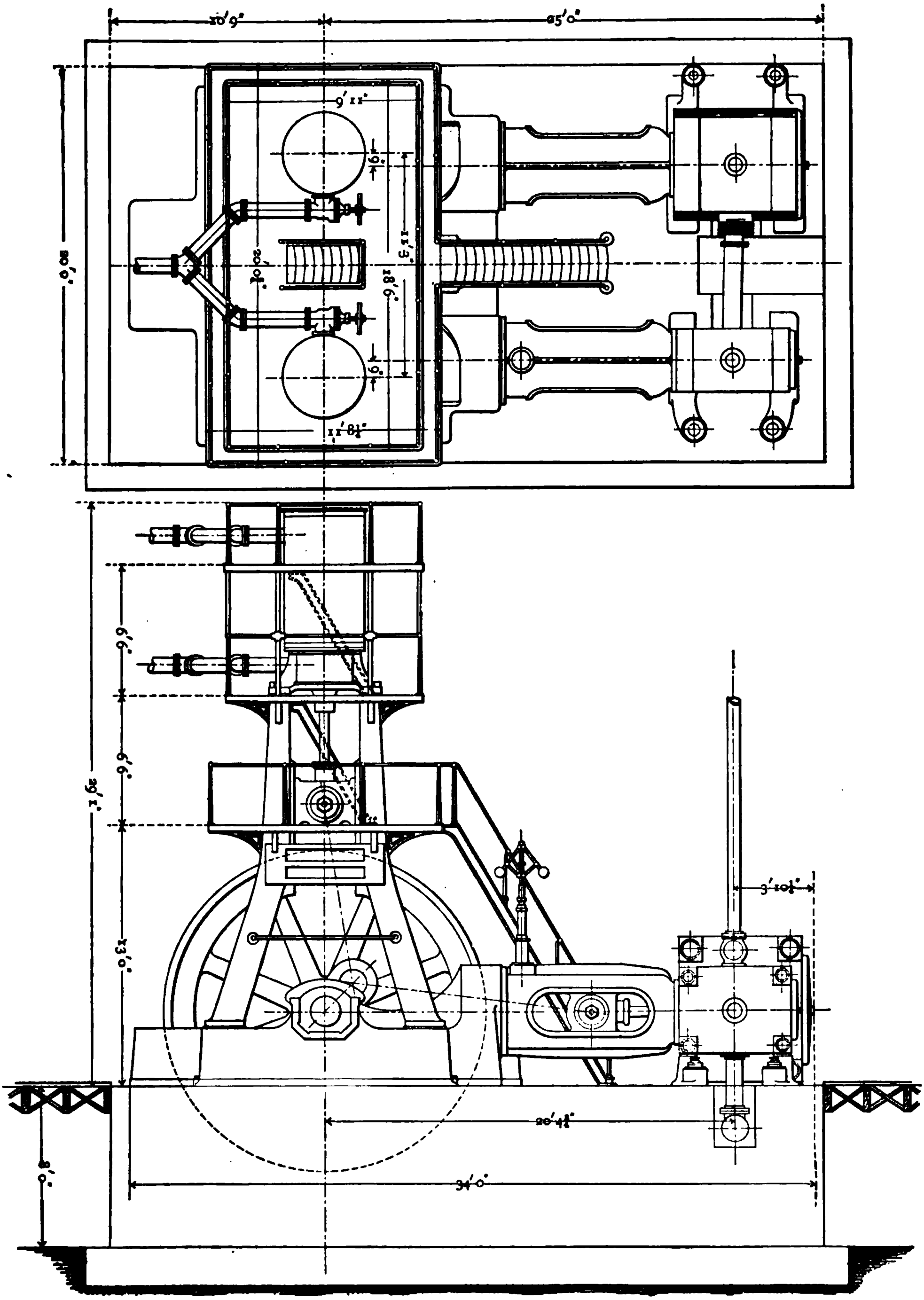
The compressor used on the standard machine, as stated above, is known as the single-acting, false, or safety-head type.

The ammonia gas from the evaporating coils of the refrigerator enters at the bottom of the cylinder, below the piston, passes up through the suction valve in the piston to the upper portion of the cylinder, where it is compressed on the upstroke of the piston and forced out through the center of the discharge valve, located at the center of the safety-head at the top of the cylinder.

The top of the piston and bottom of the safety-head are both faced off square, allowing practically flush adjustment of operation, ensuring almost complete discharge of compressed gas.

The known advantage of the safety-head is the security it guarantees against the breaking of the head in case of accidental breaking of valves or any other part of the machine, as well as an overcharge of liquid ammonia in the

FIG. 110.



PLAN AND ELEVATION 500-TON REFRIGERATING MACHINE.
York Manufacturing Co.

compressor. In such a case the safety-head is lifted from its seat, allowing the obstruction to pass through, or the lifting is repeated at each stroke until the attention of the engineer is attracted to the difficulty and the machine shut down, thereby preventing the destruction of the machine, as would be the result from such causes when solid heads are used.

The cylinder is encased in a water-jacket, the water entering at the bottom, circulating around the walls of cylinder and up over the top cover, where it overflows. The water keeps the compressor walls cool and takes care of the greater part of the heat of compression.

Both the discharge and suction valves can be inspected by the removal of the top head of the cylinder.

The diagram, Fig. 110, shows a plan and elevation of a 500-ton machine.

ILLUSTRATIONS OF YORK APPARATUS.

In view of the extensive descriptions of the various features of ammonia compressors and refrigerating apparatus that have already been given in the preceding pages, we believe that the characteristic features of the York apparatus will be readily appreciated from an inspection of the illustrations that are presented. Most of these illustrations have been used in Part I, as representative examples of the parts described.

The following illustrations will be found in Part I:

Details of compressor, Fig. 68 to 75 inclusive.

Fig. 68. Sectional view of ammonia compressor cylinder, piston and valves.

Fig. 69. Suction valve.

Fig. 70. Discharge valve.

Figs. 71 and 72. Ammonia pistons.

Fig. 73. Compressor cylinder cover.

Fig. 74. Compressor base.

Fig. 75. Compressor cylinder.

Condensers. Fig. 33 and Fig. 37.

Fig. 33. Atmospheric condenser with fore-cooler.

Fig. 37. Double-pipe condenser, "W" and "C" type.

Isometric views and ground space charts of ice plants. Figs. 24 to 28 inclusive.

Fig. 24. Plate ice-making plant—isometric interior view.

Fig. 25. Can ice-making plant—isometric interior view.

Figs. 26 and 27. Plate ice-making plant—ground space charts.

Fig. 28. Can ice-making plant—ground space chart.

TESTS.

The art of refrigeration is greatly indebted to the York Manufacturing Co. for the work it has undertaken on its own part and in offering the facilities of its entensive plant for the use of others in making extensive tests on various important features of refrigerating processes. The results that have so far been given out represent but a small part of the labor involved. In due time more will be forthcoming, to the material benefit of the art.

An idea of what has been done along this line may be obtained from the following statement:

"We have made over 600 tests of an average of ten hours each, the most of these tests requiring 12 men to operate and some as many as 25. This will give an idea of the amount of data we have collected.

"The original tests were started to determine the practical efficiency of the compressor, and also to determine practically the number of pounds of ammonia required to produce a refrigerating effect of one ton of ice, so as to establish a factor of safety.

"In addition to these tests, we have run tests to determine the speed limit of the compressor under different back pressures, the efficiency of different styles of condensers, and the efficiency of different styles of coolers. Our test plant is equipped with a double and a single-acting machine, and we have run tests on both types of machine. We have also run tests to determine the relative efficiency between a machine running wet compression and dry compression; tests to determine the effect of increasing and decreasing the lift on the

suction and discharge valves; tests to determine the effect of clearance in the compressor; and a number of other tests for various purposes.

"This has required an immense amount of work to straighten out the data obtained, and while we have had not less than two men working on the data all the time for the past three years, we are only just beginning to get things straightened out, and may find it necessary to go back and make some more tests on things on which we require additional information."

CHAPTER VII.

ANHYDROUS SULPHUROUS OR AMMONIA SYSTEM.

THE NEWBURGH ICE MACHINE AND ENGINE COMPANY.

The Newburgh Ice Machine and Engine Company manufactures apparatus of both the Pictet and Penney designs. The list includes machines adapted to the use of sulphur dioxide, machines adapted to the use of ammonia gas, and machines adapted to the use of either; machines ranging in capacity from 100 pounds per day to 500 tons; single-acting and double-acting machines; machines with single cylinder and duplex; twin connected and tandem driven machines; vertical and horizontal machines; refrigerating apparatus, applying either the direct or the indirect systems; and ice-making apparatus, including water-distilling outfit and the appliances for handling the finished frozen product; machines combined with power plant and machines adapted to be run by belt from shafting or from electric motor.

ANHYDROUS SULPHUROUS MACHINE.

The anhydrous sulphurous or sulphur dioxide (SO_2) machine is designated as the Independent Horizontal Pictet compressor.

The difference in the medium means that copper and brass may be used in any part of the construction, a great advantage in some cases in the condenser and refrigerator coils, which, from the action of acids and organic matters contained in water from certain localities, or from the sea, affect iron pipes and lead to rapid destruction. This is not the case with copper.

The fact that ammonia has a peculiar action on copper and brass, tending to dissolve and eat them away, precludes the use of these metals in cases where the same might be desirable.

Neither the oxide nor the ammonia has any effect upon iron or steel.

The working gas pressure for the oxide is between one-half and one-third less than for ammonia. No superiority for either is claimed.

The construction of the machine is along the lines of compressors for ammonia, such as have already been described. The machine is horizontal, double acting.

FIG. 111.

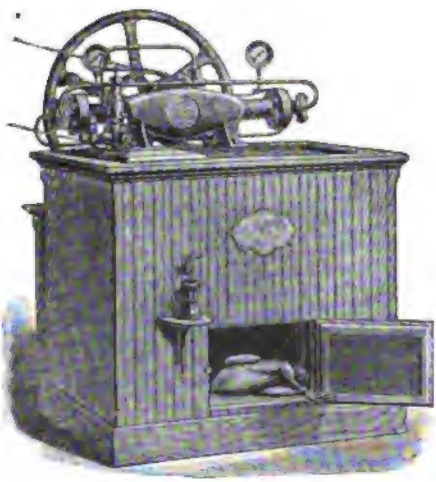
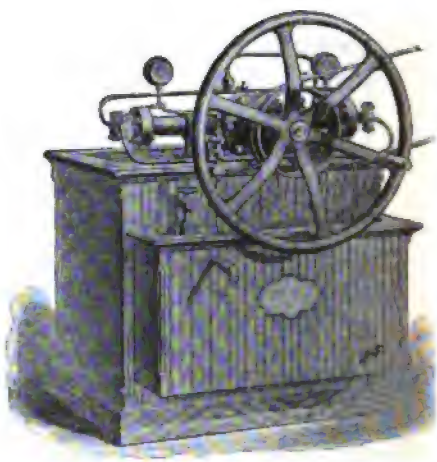


FIG. 112.



SELF-CONTAINED ICE AND REFRIGERATOR MACHINES.

Special features in regard to valves may be mentioned, as follows:

Valves of steel placed in removable steel cages, cushioned adjustment.

Accessibility of valves. By simply removing two bolts the cage with valve may be withdrawn and replaced by a duplicate.

Interchangeability of valves: suction valves being interchangeable with discharge values, and vice versa, on which account the action of the pump may be reversed to permit of forcing gas from one part of the system to the other.

SELF-CONTAINED ICE AND REFRIGERATOR MACHINES.

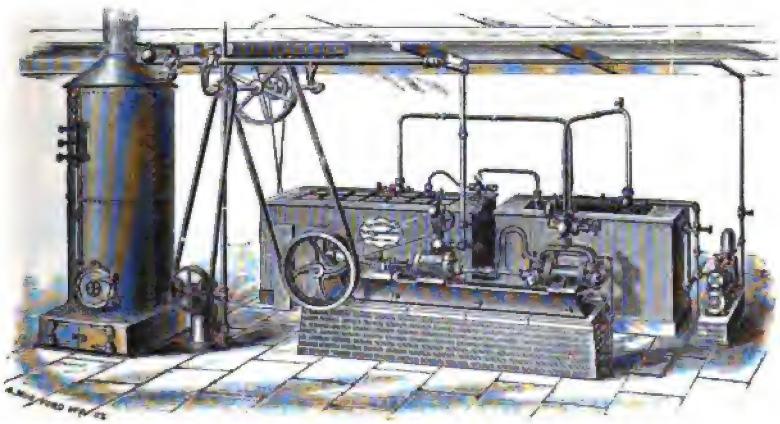
The smaller machines are self-contained, the machine being mounted directly upon the refrigerator. See Figs. 111 and 112. Ice in cakes of from 5 to 25 pounds is frozen in the upper part of the refrigerator, and stored in compartments in the same. The plant includes compartments for cooling drinking water and for storing provisions, as in a domestic refrigerator.

The condenser is mounted at the side.

Machines of this type range in capacity from 250 pounds to 1000 pounds per day.

These plants are shipped already assembled and ready for operation, even to being charged with gas.

FIG. 113.



SMALL REFRIGERATING PLANT. INDIRECT OR BRINE SYSTEM.

SMALL REFRIGERATING PLANTS.

Small and medium-sized plants are generally made up with horizontal double-acting compressors, the small plants operating with direct expansion and the medium-sized plants either direct or indirect with brine circulation. A small plant adapted to this latter system is shown in Fig. 113.

ENCLOSED ICE MACHINES.

The enclosed ice machine, Figs. 114 and 115, is designed with two single-acting, duplex compressors, either belt or direct steam driven. It is intended to meet the demand for small outfits with unskilled attendance. All the working parts are tightly enclosed, the end of crank shaft projecting through the side of the case to receive the driving pulley or the connection to engine shaft. These features mentioned are so combined that there is but one stuffing-box to the whole machine.

FIG. 114.

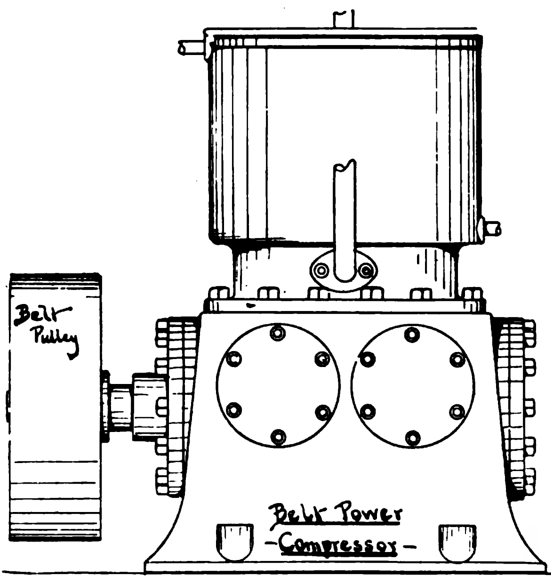
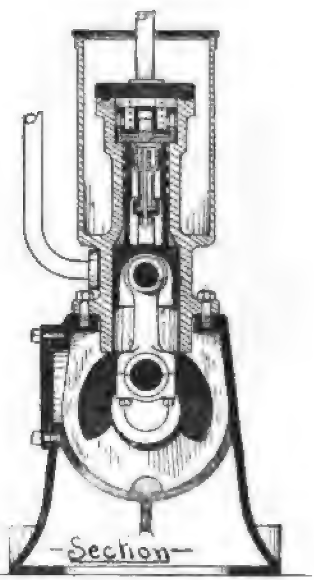


FIG. 115.



ENCLOSED ICE MACHINE.

These machines are made for as low a capacity as 100 pounds per day.

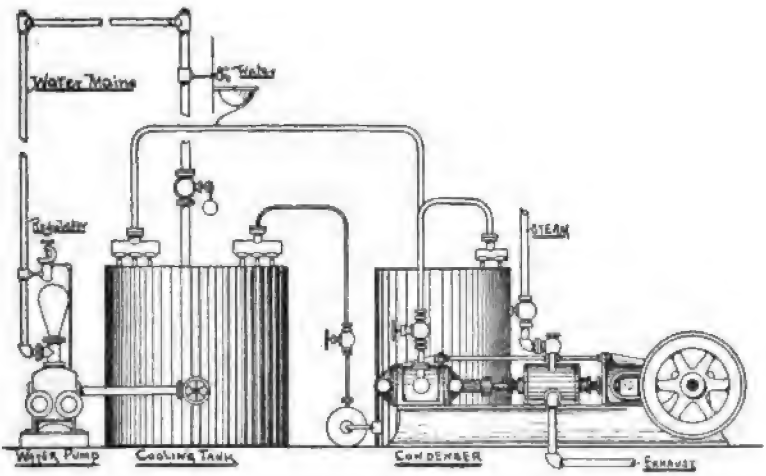
VERTICAL SINGLE-ACTING REFRIGERATING MACHINES.

The vertical single-acting refrigerating machine, Fig. 66, Part I, Chapter XVIII, is of a type that has been familiar for a dozen years or more. Machines of this type in operation are numerous, and many of them of large capacity.

WATER COOLING OUTFIT.

One of the most evident applications for a refrigerating plant is for the cooling of water. The application certainly does not call for extended reference. A plant adapted to this purpose is shown in Fig. 116. Among the locations where there may be a demand for such an outfit, operating either

FIG 116.



WATER COOLING OUTFIT.

directly or indirectly, may be included office buildings, hotels, creameries and aquariums.

DISTILLING APPARATUS.

The distilling apparatus for producing pure water for ice production and family use, demands some explanation.

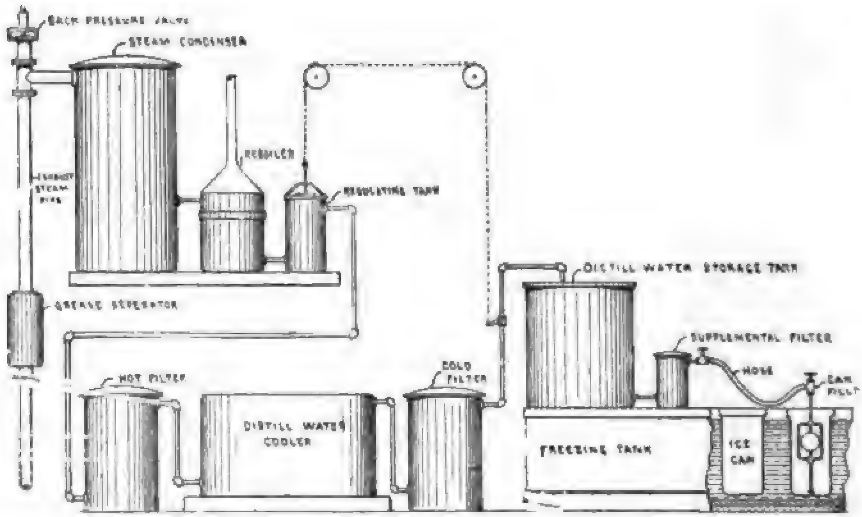
The object of distillation is, of course, to eliminate the impurities from the water, this being done by driving the water in the form of vapor off from the impurities.

In plants operated by steam it is policy to utilize the exhaust steam as part of the supply for ice production. This necessitates the removal of the grease from the water to render it satisfactory for use.

A thorough distillation includes reboiling, filtering, purifying and deodorizing.

The course followed by the exhaust steam from the exhaust pipe to the freezing can may include the following apparatus in order: Grease separator, steam condenser, reboiler, regu-

FIG. 117.



PENNEY'S PURE WATER DISTILLING APPARATUS.

lating tank, hot filter, distilled water cooler, cold filter, distilled water storage tank, supplemental filter, and ice can filler. The course outlined may be followed by reference to Fig. 117.

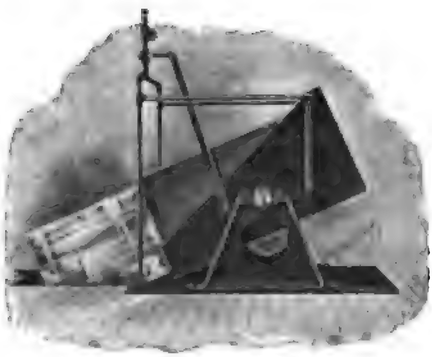
AUXILIARY APPARATUS.

Among the auxiliary apparatus may be mentioned a geared hand hoist and traveling crane, and an automatic ice can dump, shown in Figs. 118 and 119 respectively.

FIG. 118.

HAND HOIST AND TRAVELING CRANE.

FIG. 119.



AUTOMATIC ICE CAN DUMP.

CHAPTER VIII.

THE CARBONIC ANHYDRIDE SYSTEM.

J. & E. HALL SYSTEM.

THE carbonic anhydride system of artificial refrigeration as produced by the J. & E. Hall Company of England is well described by a member of the company, Mr. E. Hesketh, M. Inst. C. E., in a paper read before the British Association, from which we largely quote:

"In 1889 the author, in conjunction with his co-directors in the company of J. & E. Hall, Limited, of Dartford, Kent, introduced their first carbonic anhydride (CO_2) machine, which was made to the design and under the patents of Mr. Franz Windhausen, of Berlin. Since then very considerable improvements have been made, and the system is now firmly established, and far beyond the experimental stage (as evidenced by the fact that during the past twelve months 129 machines of all sizes have been supplied by the author's company)."

In common with many other refrigerating machines, the principle of action is the vaporization of a volatile liquid at a temperature below that of the material to be cooled, the latent heat necessary for vaporization being obtained from such material which is thereby cooled. The resulting vapor is then recompressed and brought back into liquid state, thus completing the cycle. (See Fig. 120.)

The essential parts of a machine are:

An evaporator, consisting of lengths of pipe, inside which the carbonic acid evaporates, absorbing heat from the material to be cooled which surrounds these pipes.

A compressor, in which the carbonic acid vapor is recompressed to such pressure as may be required to liquefy it at the temperature of the cooling water available.

A condenser, consisting, like the evaporator, of lengths of

pipe containing the carbonic acid, and outside which circulates the cooling water which carries off the latent heat given out during liquefaction.

Some details of the machines are as follows:

Compressor. The compressors for the large machines are bored out of solid steel forgings, partly to secure strength, but principally on account of greater certainty of soundness of the material, and to provide a perfect bore in which may work the cup leathers with which the pistons are provided.

FIG. 120.

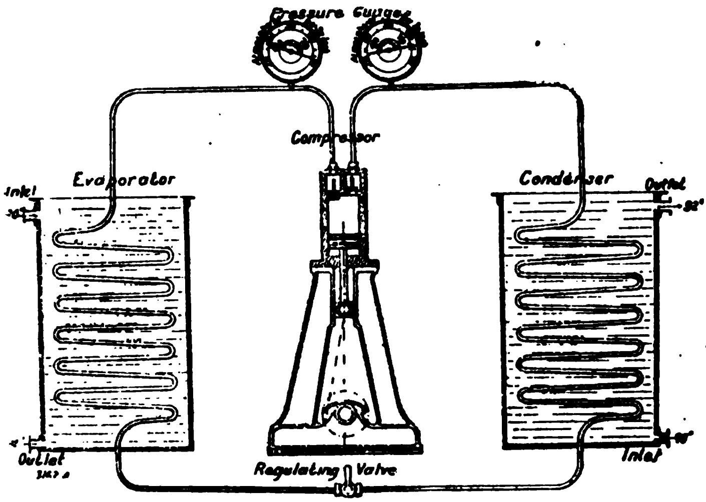


DIAGRAM OF CARBONIC ANHYDRIDE SYSTEM.

Compressors of smaller machines are cast in a special bronze, which secures the two essentials of soundness and hardness. The suction and delivery valves are identical for facilities of interchange.

Gland. The gland is made gas-tight by means of two cupped leathers on the compressor-rod. Glycerine is forced into the space between these leathers at a pressure superior to the greatest pressure in the compressor, so that whatever leakage takes place at the gland is a leakage of glycerine either into the compressor or out into the atmosphere, and not a leakage of gas. What little leakage of glycerine takes place into the

compressor is advantageous, inasmuch as it in the first place lubricates the compressor, and in the second place it fills up all clearances, thereby increasing the efficiency of the compressor.

The method of obtaining this superior pressure consists of the following device: A bored cylinder is fitted with a piston, and connected with one end of this piston is a rod which passes through a gland in one end of the cylinder. From the other end of the cylinder a connection is made to the CO_2 condenser, whereby the condenser pressure is exerted on the plain end of the piston. Into the cylinder on the gland side is forced glycerine. Owing to the difference in area of the two sides of the piston, a greater pressure per square inch of glycerine is required to keep the piston in equilibrium. A connection is made from the glycerine space to the space between the leathers in the compressor gland.

In order to replace the glycerine which leaks out of the glycerine lubricator, there is a small hand hydraulic pump, a few strokes of which are required to be made every four or five hours, as may be indicated by the position of the glycerine piston rod. This form of gland is now in constant use on nearly 300 machines.

Separator. Any glycerine which passes into the compressor, beyond what is necessary to fill the clearance spaces, is discharged with the gas through the delivery valves. In order to prevent this passing into the condenser coils, all the gas is delivered into a separator, and made to impinge against the sides of this vessel. The glycerine adheres to the sides and drains to the bottom of the vessel, whence it is drawn off from time to time; meanwhile, the compressed gas passes off by an opening at the top on its way to the condenser.

It may here be remarked that glycerine has no affinity for CO_2. Hence it undergoes no change in them achine, and there is therefore no fear of the coils becoming clogged by any small amount of glycerine which might be carried over in spite of the separator.

Condenser. This consists of coils of wrought-iron hydraulic pipe, usually of $\frac{13}{16}$ in. bore, which are either placed in a tank

and surrounded by water, or are arranged so that water trickles over them, forming the well-known atmospheric condenser. These coils are welded together into such lengths as to avoid altogether any joints inside the tank, where they would be inaccessible. The welding of these pipes is, by the way, performed by the electrical method, which gives very good and reliable results.

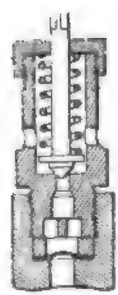
In connection with the condenser, one very important advantage of CO_2 machines is apparent, for as CO_2 has no chemical action on copper, in the numerous cases where sea water only is available for condensing purposes, that metal is used in the construction of the coils.

Evaporator. This also consists of nests of wrought-iron hydraulic pipes welded up into long lengths, inside which the CO_2 evaporates. The heat required for evaporation is usually obtained either from brine surrounding the pipes, as in cases where brine is used as the cooling medium, or else from air surrounding the pipes, as in cases where air is required to be cooled direct.

Regulating Valve. Between the condenser and evaporator there is a regulating valve for adjusting the quantity of the liquid CO_2 passing from the condenser.

Safety Valve. In order to enable the compressor to be opened up for examination of valves and piston without loss of CO_2, it is necessary to fit a stop valve on the suction and delivery side, so as to confine the CO_2 to the condenser and evaporator. It is, of course, possible for a careless attendant to start the machine again without opening the delivery valve, and in such case an excessive pressure would be created in the delivery pipe, from which there would be no outlet. To provide against this danger a safety device is adopted, consisting of an ordinary spring safety valve, at the base of which is a thin copper disc, which is designed to

FIG. 121.



SAFETY VALVE. CARBONIC ANHYDRIDE SYSTEM.

burst at a pressure of 1,950 pounds. This disc is made perfectly gas-tight, an object which could not be obtained by the spring safety valve alone, and the latter only comes into play when the disc is ruptured. Great care is necessarily exercised in making the discs, to provide against variation in strength due to any variation either in the thickness or hardness of the copper sheets out of which the discs are made, and it is the practice to test every disc by hydraulic pressure up to 1,350 pounds, and to burst one disc in every 12, recording the pressure at which it is ruptured.

Joints. With regard to the joints to withstand the high pressures, those which are not subject to a high temperature can be made absolutely tight with any suitable material, such as leather, but with the hot joints trouble was at first experienced in getting a material to withstand the heat, and also with the necessary elasticity to insure the joint being perfectly tight, not only when it is hot, but also when it is cold. This has been entirely overcome by the adoption of joining rings turned out of a copper alloy, which completely fulfills the requirements of the case. The absolute tightness of all joints is effectually tested by brushing them over with soap and water, the slightest leak being thereby discovered.

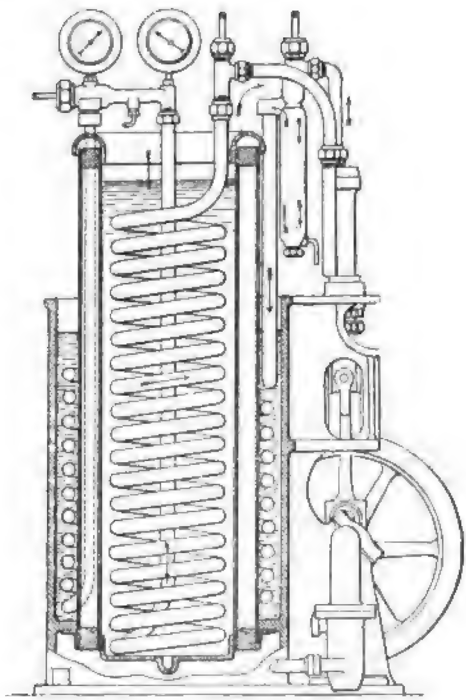
Testing Parts. Very careful tests are carried out by the company to insure perfect soundness of all parts subject to the gas pressure. The working pressure varies from about 750 pounds per square inch in temperate climates, with water at 50 degrees Fahrenheit, to about 1,125 pounds, with water at 84 degrees, as is usual in the tropics. This is, of course, sometimes exceeded in exceptionally hot localities. Owing to the very small diameter of all parts, even in large machines, there is no difficulty in securing a very ample margin of strength. All parts of machines subject to the pressure of the CO_2 are, in the first place, tested for strength by hydraulic pressure to 3,000 pounds per square inch, and they are then again tested while immersed in warm water by air to 1,350 pounds per square inch, whereby the slightest porosity which might exist in any of the materials is at once detected by air bubbles ascending through the water.

TYPES OF MACHINES.

The machines are made in 37 different sizes and designs to suit the various requirements.

The large single-type machines are usually arranged with compound steam cylinders arranged tandem, and driving by a tail-rod the CO_2 compressor, the tanks containing the condenser and evaporator being separated from the machine.

FIG. 122.



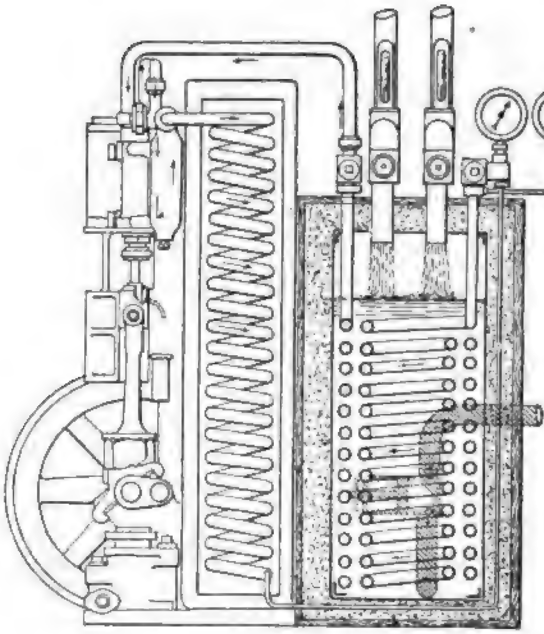
SMALL VERTICAL MARINE TYPE MACHINE.

The large duplex machines are arranged with triple-expansion engines, the high and intermediate cylinders being on one side, and the low-pressure cylinder on the other, the two compressors being driven by tail-rods from these cylinders. In connection with each CO_2 compressor is a condenser and

evaporator, so that there are two quite complete and independent CO_2 systems. The steam condenser is arranged in the front part of the bed.

The smaller duplex machines are similar to the above, but with compound steam cylinders, and the CO_2 condenser coils are fitted in the bed of the machine, making a compact arrangement.

FIG. 123.



SMALL LAND TYPE MACHINE.

This duplex machine is also made of the vertical type in the smaller sizes.

The small vertical marine type machine consists of a single vertical steam cylinder with compressor arranged alongside of it, both secured to a casting containing the condenser coils, which are made of copper, and behind this casting is another secured to it, containing the evaporator coils, the whole making a very compact and accessible design. Fig. 122.

The smaller land type machine consists of a rectangular cast-iron tank, with which is cast the frame carrying the compressor. Inside the rectangular tank are the condenser coils, and inside them again is a double tank with insulation between, and the evaporator coils in the center. This type of machine is sometimes arranged with horizontal steam engine attached at one side of the main casting and driven on to the end of the crank-shaft. Fig. 123.

In all designs the condenser and evaporator coils are made of long lengths of pipe without joint, so that there are no joints whatever that are inaccessible.

PERFORMANCE OF MACHINES.

The duty of all refrigerating machines varies with the range of temperature through which the agent is caused to pass in its cycle. Thus the British thermal units abstracted by a machine of given size, will be greater the less the range of temperature, and *vice versa*, and this variation in efficiency varies with different materials used as the refrigerating agent.

Trials of one of three machines erected in London gave the following results:

Each machine has one double-acting compressor, and the motive power consists of a single-cylinder steam engine, 15 inches in diameter by 24-inch stroke, the compressor piston being driven by a tail-rod. When running at 65 revolutions, this machine eliminated 519,795 British thermal units when cooling water from 64.6° Fahr. The initial temperature of the water used in the condenser was 64.4° Fahr., and the outlet 77.55° Fahr., a considerable rise due to the restricted quantity of water used.

The indicated horse-power of the steam cylinder was 37.13, but from this has to be deducted the power required for driving a water pump estimated at 3.128.

The engine is non-condensing, working with a steam pressure of 60 pounds, and a back pressure of some five pounds above the atmosphere, the waste steam being used for heating, so the

size of cylinder is larger than would ordinarily be required for the duty obtained.

It is to be noted that the figures are obtained from a ma-

FIG. 124.

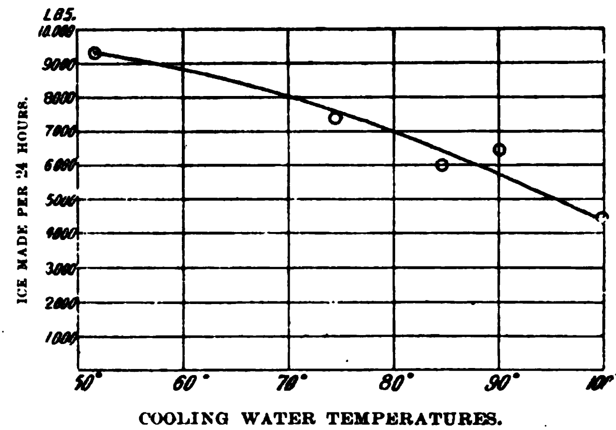
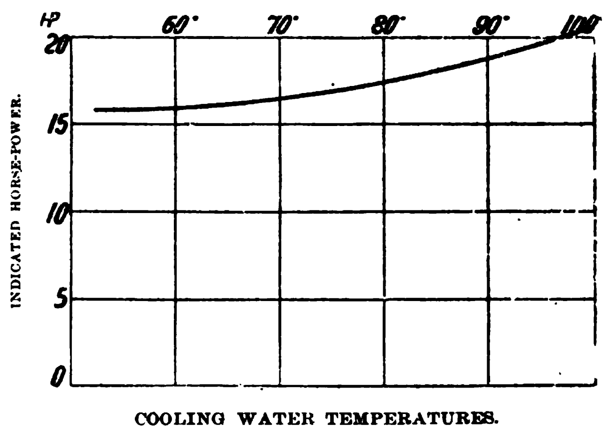


FIG. 125.



chine in ordinary work, and not from one specially arranged for testing purposes. No doubt stirring gear in the condenser and evaporator, to cause great rapidity of flow of water over the coils, would increase the efficiency.

Several tests were made at different times of a nominal 4-ton ice-machine, the first machine made by the company in 1889. The machine was tested making ice with inlet cooling water at five different temperatures, viz.: 52°, 75°, 85°, 90° and 100° Fahr. Each test extended over some days, during which careful records were kept, the ice accurately weighed, and the steam engine indicated. The following is an epitome of the results obtained:

Inlet Cooling Water. Deg.	Ice Produced per 24 Hours. Lbs.	Indicated Horse-power of Steam Engine.
52	9,360	15.62
75	7,382	16.03
85	6,000	17.48
90	6,408	19.31
100	4,536	20.44

Curves made up in accordance with these values are shown in Figs. 124 and 125.

Besides driving the compressor, the engine had to work both water and brine pumps, and an air pump, and stirring gear in the brine cooler. The water put into the ice moulds was in each experiment at the same temperature as the inlet condensing water.

A test was made of another machine cooling water from 50° Fahr., while the condensing water was gradually increased from 61° to 100°. The results show the British thermal units abstracted per hour varying from 49,875 with condensing water at 60° Fahr. to 24,867 with condensing water at 100° Fahr.

HARMLESSNESS OF CARBONIC ANHYDRIDE.

The use of any refrigerating agent requires also to be considered from the point of view of its effect upon human health and life; for whatever material used, there will be times when an escape occurs into the engine room, *e. g.*, when the compressor is opened up for inspection of valves, etc.

In this connection it is sufficient to say that it is a common practice in the workshops, after testing a carbonic anhydride

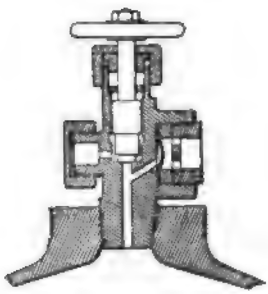
machine, to blow out the whole charge of CO_2 without the least inconvenience being experienced by the workmen.

CO_2 FLASKS.

As far as cylinders for conveying CO_2 are concerned, danger can only occur from two causes: (1) insufficient strength to stand the normal strain of the contained gas; or (2) overcharging, and consequent abnormal strain.

1. With regard to the first, a method of testing which is now applied to CO_2 flasks, whereby, when the proof strain is put on, any permanent set due to straining beyond the elastic limit is at once detected. The cylinder undergoing the test is encased in a closed water jacket, from which rises a long glass tube of small bore with open end. As the cylinder expands under the test pressure, the water rises in the glass tube, and when the pressure is relieved the water in the tube returns to its original level unless any permanent set has taken place.

FIG. 126.



VIEW OF CYLINDER OR TANK VALVE WITH SAFETY DISC.

Cylinders for carrying liquid CO_2 are tested to 3,000 pounds per square inch.

2. The overcharging of cylinders is always a possible contingency, though it is due to the manufacturers to say that they take every precaution to prevent such. The possibility should, however, be guarded against.

In order to prevent the possibility of undue pressure occurring, there is introduced into the cylinder valve a safety disc, (Fig. 126) which, whether the valve is open or closed, is always exposed to the pressure in the cylinder, and forms, in fact, a weak point which will relieve any excessive pressure.

CHAPTER IX.

THE CARBONIC ANHYDRIDE SYSTEM.

KROESCHELL BROTHERS.

MESSRS. KROESCHELL BROTHERS, of Chicago, Ill., produce several styles and sizes of refrigerating machines operating with carbonic anhydride and also all that goes with a complete plant for ice-making and refrigerating.

The machine "is patented in all the progressive countries on the globe, and is in successful operation on land and sea, in tropical and northern countries, in fact everywhere where human necessities and the demands for the comforts of life require the service of a reliable ice and refrigerating machine."

STUFFING BOX.

The patent referred to is Sedlacek's patent on details of the stuffing box.

The construction of the stuffing box has received the most careful consideration, and is to-day so highly developed that it requires no special care. A special oil, which has demonstrated its excellent qualities as a lubricant and sealer is used for this purpose, and by a very ingenious arrangement the stuffing box is relieved of all gas pressure. A continuously working pump controls the pressure. It seals the stuffing box thoroughly with oil, and prevents the loss of gas through the stuffing box.

The pump is so constructed that only the required amount of oil is pumped into the stuffing box, so there is no waste of same.

Whatever leakage does take place through the stuffing box is a leakage of oil and not of gas, and the small leakage of oil into the cylinder is advantageous, inasmuch as it lubricates

the compressor in the first place, and in the second place it fills up all clearances, so that the full volume of gas is discharged at every stroke.

SEPARATOR.

Any oil which passes into the compressor beyond which is necessary to fill up the clearance spaces, is discharged with the gas through the delivery valves. In order to prevent this going into the system, all the liquid passes through a separator, in which the oil drains to the bottom, whence it is drawn off from time to time.

It may be remarked here that this oil has no affinity for carbonic anhydride, hence it undergoes no change in the machine, and there is no chance of the condenser coils becoming clogged up.

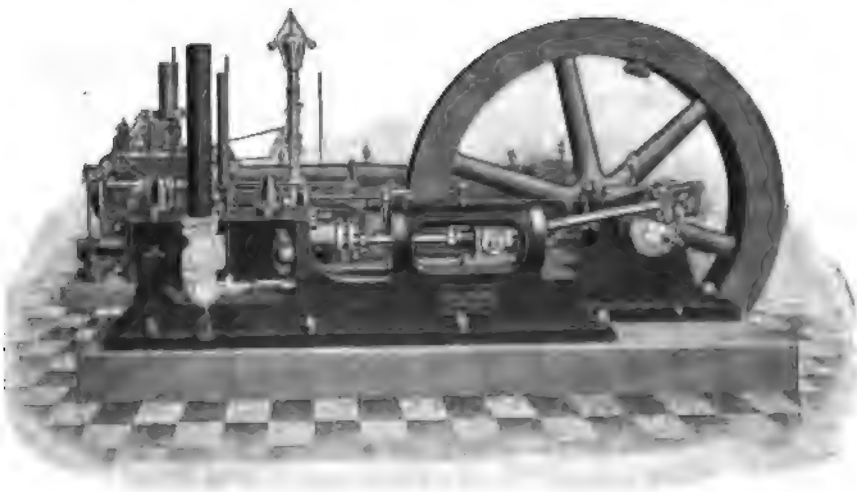
CONSTRUCTION OF THE CARBONIC ANHYDRIDE MACHINE.

Compressors above two tons daily refrigerating capacity are of the horizontal, double-acting type. The cylinder is made of semi-steel, and has a return gas chamber through which the cold return gas passes. It enters this chamber at a temperature sufficiently low to remove the heat of compression from the compressing cylinder, keeping the same at a uniform temperature, and thereby preserving the piston packing. The return gas chamber also adds to the strength of the compressing cylinder, as it relieves the same of a greater part of its strain, because the pressure of the return gas without the cylinder is nearly the same as the pressure within the cylinder, according to the formula "surface times pressure," hence the strain on the material of the compression cylinder is almost entirely eliminated, and, therefore, a bursting is out of the question. The working pressure varies from about 50 to 70 atmospheres. Owing to the very small diameter of all parts, even in large machines, there is no difficulty in securing an ample margin of strength. It should be readily apparent that a high pressure in a small cylinder is even less dangerous than a relatively lower pressure in a larger cylin-

der. All parts subject to the pressure of carbonic anhydride are tested to three times the working pressure, thus giving perfect safety.

Pistons are made of the best forged steel, with rod tempered so that there will be no wear, and consequently no leakage of gas through the stuffing box on account of a worn and faulty piston rod. The shaft, crank, pins, connecting rod and valves are also made of solid steel forgings, and are interchangeable.

FIG. 127.



STANDARD PATTERN OF HORIZONTAL DOUBLE-ACTING COMPRESSOR—CARBONIC ANHYDRIDE SYSTEM.
Kroeschell Bros.

Machines of this type are shown in Figs. 127 and 128. The former shows the style of machine used for the larger capacities, while the latter shows the marine type, built from two to ten tons capacity.

SAFETY.

In communication with the high-pressure side is a safety valve for the purpose of insuring the cylinder against accidents of any kind. This safety valve is placed in the high

pressure channel, between the gas discharge valves and the discharge stop valve, which is fitted to the delivery side of the compressor. The purpose of this valve is two-fold. It will relieve the cylinder and also the system of a pressure that has risen above the normal in case of a fire or through lack of condenser water, and it will also guard against carelessness of the operator who attempts to start the machine without opening the discharge stop valve. As the action of the safety valve is accompanied by a loud report, it will direct the attention of the operator towards the machine, so that no great loss of gas can occur. The safety valve consists of a housing, at the base of which is a thin disc, which is designed to blow off at a pressure considerably below that to which the machines are tested.

Each side of the cylinder is fitted with a stop valve, so that the cylinder may be opened up at any time for inspection of the piston without pumping back or any of the other preparations necessary with ammonia machines.

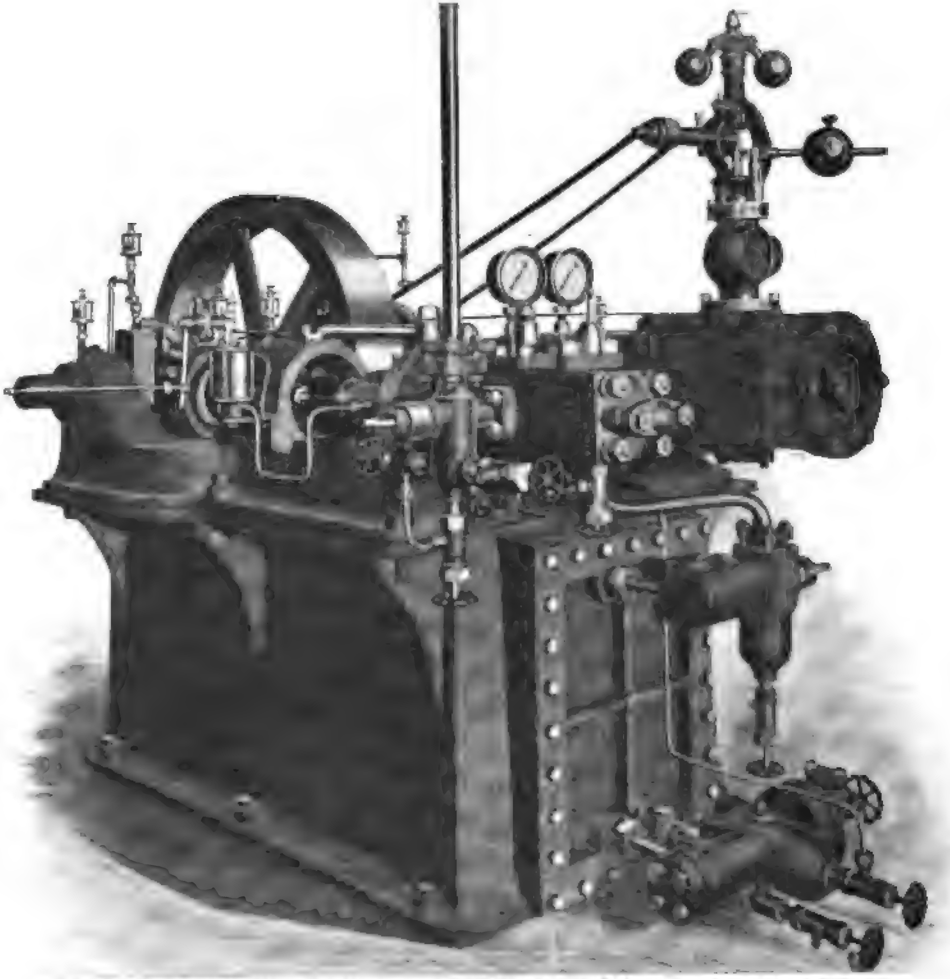
"NORTH POLE MACHINES."

Fig. 129, represents No. 1, No. 2 and No. 3 North Pole Miniature Ice and Refrigerating Machines. These machines consist of two vertical single-acting compressors located inside the condenser tank.

The cylinders are made of semi-steel, and are provided with patented stuffing-box, sealed with glycerine. Each cylinder has a suction and discharge valve, all located at the top of a joint cylinder head, which makes them easily accessible. The valves are made of forged steel, are of special design, and combine strength with lightness. On one side of the cylinder head is the filling valve, which can be easily connected by means of a short pipe with the Carbonic Anhydride drum, now in common use. The suction pipe, as well as the condenser coil, has stop valves, so that the suction and discharge valves in the cylinder head can be examined without loss of gas.

The condenser, which consists of a spiral coil made of extra

FIG. 128.



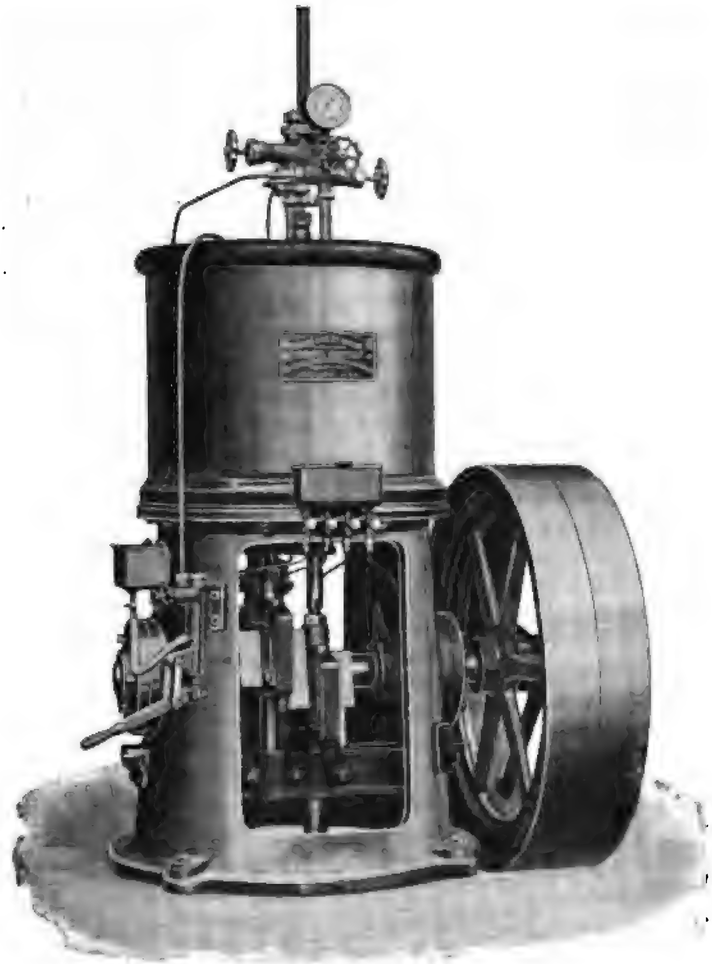
CARBONIC ANHYDRIDE MARINE TYPE COMPRESSOR, FROM TWO TO TEN TONS.

BUILT IN FIVE SIZES.

(To face page 272.)

strong iron pipe surrounding the compressor, is connected on one end with the discharge side of the same, while the other

FIG. 129.



NORTH POLE MINIATURE ICE AND REFRIGERATING MACHINE.
Front View.

end is connected with the combined separator and liquid receiver, located on the back of frame.

The bearings of the crank shaft are incorporated in the cast iron frame supporting the condenser tank. The double-throw crank shaft actuates the compressor pistons by means of strong yokes having guides on the lower side, thereby doing away with the long connections otherwise made necessary, by connecting rods and cross-heads, making the compressor a compact, strong and simple machine. The double-throw crank shaft is of forged steel overhanging one side of the frame to receive the band wheel and loose pulley.

The receiver is a strong wrought-iron cylinder with a stop valve located on top, and blow-off cock on the bottom. By means of the latter, the glycerine carried over from the cylinder can be drawn off.

On the top of the condenser tank is a gauge mounted upon a three-way valve, connecting same either with the compression or suction side of the machine.

On the side opposite to the pulleys is a small hand pump, by operating which the cylinders are lubricated. All these machines are fitted with a safety valve, so that even the possible neglect or ignorance of the attendant is provided against, and nothing in the nature of an accident can possibly occur.

All these machines are fitted with an automatic lubricating device.

These machines are very compact, and are shipped ready to be started into immediate operation, upon making the necessary belt and pipe connections. They may be operated either by steam power, electric power, gas engines, or in fact almost any form of power generating machinery. They are also built direct connected with a vertical steam engine or geared electric motor.

APPLICATION AND PLANS OF OPERATION.

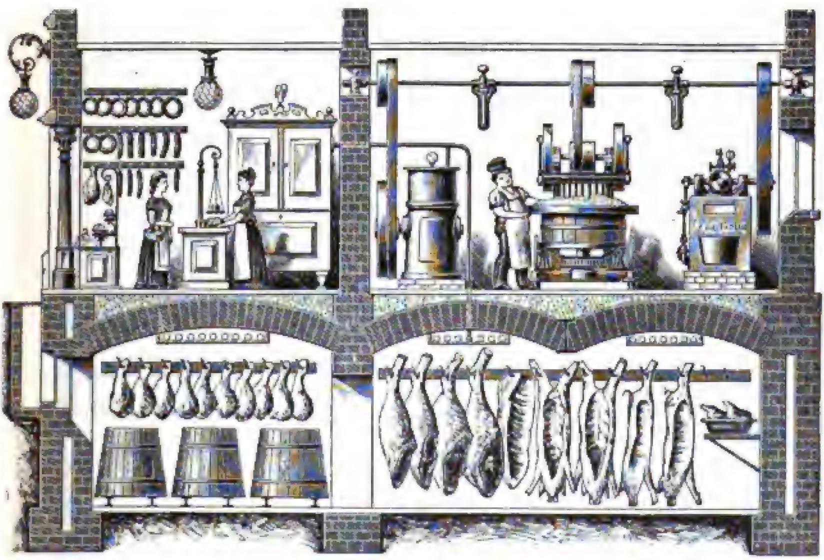
Here would be included practically the entire list of uses of mechanical refrigeration and methods of application, among which may be mentioned direct expansion; forced brine circulation; cold air circulating system; can ice-making; plate ice-making; marine refrigerating; cold storage; restaurants

and hotels; butcher shops, see Fig. 130; milk cooling; water cooling; and breweries.

COLD AIR CIRCULATING SYSTEM.

The circulation of cold air is also considered an indirect system of refrigeration, for the reason that the air is cooled in separate chambers on direct-expansion cooling coils (sometimes on brine coils), and then circulated through the rooms by means of air ducts and fans. The velocity of the air does not

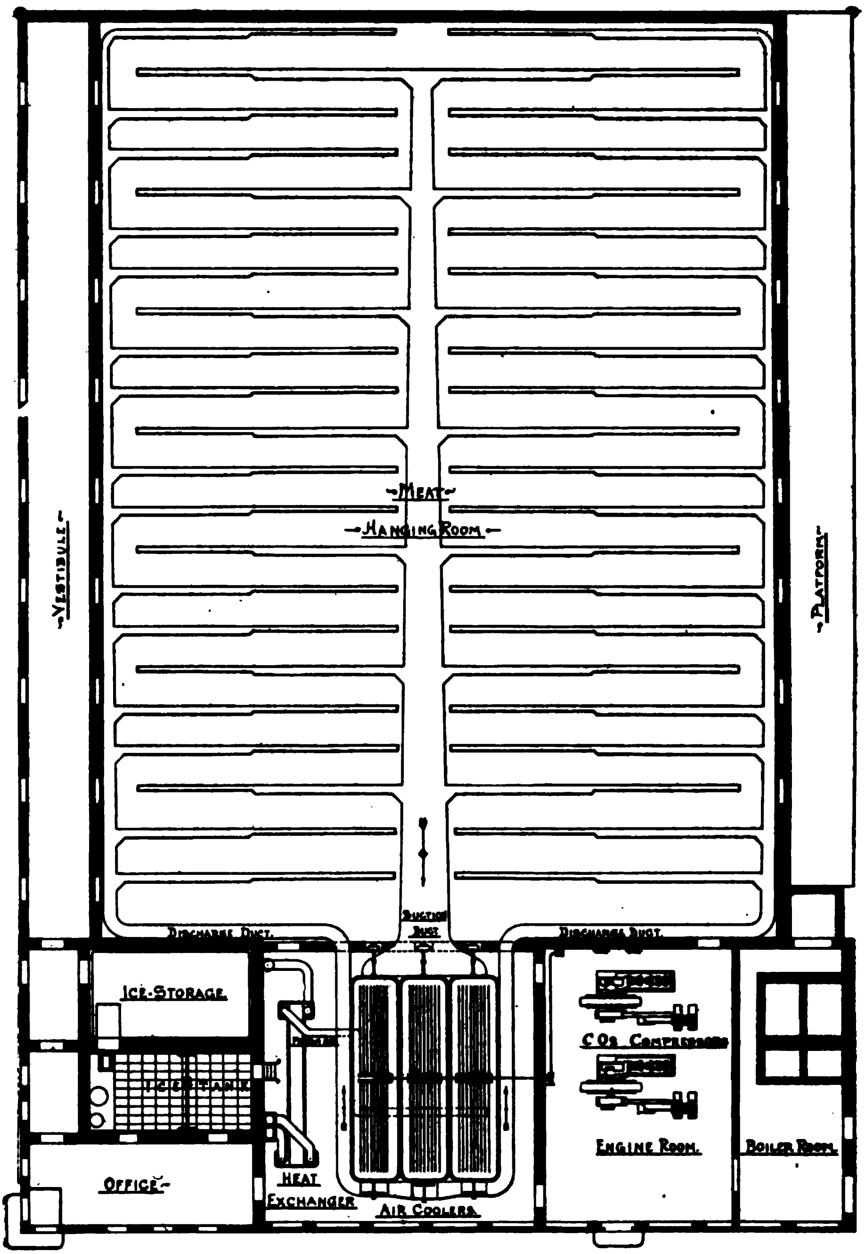
FIG. 130.



MINIATURE CARBONIC ANHYDRIDE REFRIGERATING MACHINE IN CONNECTION WITH A BUTCHER SHOP.

exceed 30 feet per second, so that a gentle circulation exists in the rooms, which is admirably adapted to the preserving of goods, especially eggs, meats, butter, cheese and vegetables. An arrangement to change the air whenever necessary, and to expel vitiated air, is provided for, so that the air in the rooms is always fresh and pure. The rooms refrigerated by this system are free from dampness and foul odors, and it is said that meats subject to air cooling are very rapidly chilled, and that the shrinkage of goods is less than with any other system.

Fig. 132.



GENERAL ARRANGEMENT OF A MODERN COLD-AIR CIRCULATING PLANT.

This system also has the advantage of arranging the expansion coils in a compact manner, which allows an easy control of valves and temperatures. It has found great favor with the authorities of large cities conducting their own slaughter houses, especially in Germany, and reports of elaborate and exhaustive tests show admirable efficiency and economy.

In the United States, however, this system is in use only to a limited degree though there is noticeable at present a tendency to look into its merits more fully.

The reason for the conservative adherence of the large refrigerating corcerns to the old brine, and more recently to the direct expansion system, may again be found in the fear that a leaky joint may saturate the circulating air with the destructive ammonia vapors, and so cause enormous damages in every room.

Carbonic anhydride refrigerating machinery is free from this danger, and is, therefore, well adapted for the cold-air circulating system.

The illustration, Fig. 132, shows a diagram of a cold-air circulating plant. The independent air coolers are composed of a system of direct expansion pipes, calculated for a certain amount of work, and so arranged that the connections are made outside of the coolers. The coolers are accessible and provided with light and a window for observing the freezing and thawing of the pipes without entering the cooler. Each cooler is provided with a large valve for regulating the air passage and for closing off for thawing.

Warm air contains a greater percentage of moisture than cold air. This moisture will be deposited on the cold direct expansion pipes, and must be thawed off from time to time.

Large fans take care of the circulation of the cold air, and force the same through the two main inlet ducts, running along both sides of the room, while the suction duct, located in the center of the room, carries back the air to the coolers to be re-cooled.

In order to renew the air from time to time, a heat exchanger is employed. The exchange circulation is produced by fans, and in such a manner that the incoming air is forecooled by the outgoing spent air.

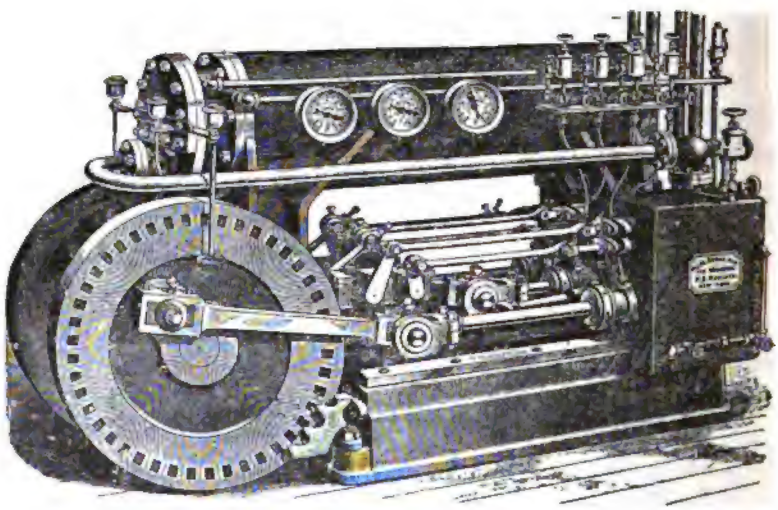
CHAPTER X.

THE COMPRESSED AIR SYSTEM.

THE ALLEN DENSE-AIR ICE MACHINE.

THE Allen dense-air ice machine is a machine which has with satisfaction and safety been placed in the main engine room of a steamer, and is attended by the regular engineers, along with their work, while the meat room is in a distant, convenient portion of the vessel. Thus it avoids the nuisance of carrying specialists, who generally manage to escape the

FIG. 133.



ALLEN DENSE-AIR ICE MACHINE.

control of the chief engineer. It contains only common air, at reasonable pressures, and only machinery similar to usual steam-engine machinery, and there are no auxiliary pumps or other machinery outside of the ice machine. Fig. 133 shows a machine set up complete, ready for use.

The cold air is carried through pipes of small size to the ice-making room and to the meat room, and requires no manipulation of any kind. The filling of the ice cans with water and emptying the frozen ice blocks out of them, and an occasional look at the temperature of the meat room, is all the attention given to the cold apparatus outside of the engine room.

The use of these machines enables passenger steamers to purchase in New York (the best and cheapest market) or at their home port the meat-supply for the whole voyage, including the return. Brazilian steamers regularly carried meat to several hundred miles beyond Rio de Janeiro and again to New York, spending seventy days virtually in the hottest portions of the tropics, and kept the same in prime condition for the first-cabin table, better than is done on a single voyage from Havana to New York in the usual icehouse. The wasteful and unpleasant trimming of the meat is done away with. The meat-house is always fresh, pure and dry. Fish, light meats, game and poultry can be kept for a very long time, and can, therefore, be bought wherever it is most profitable to do so. For yachts on long voyages it is the greatest of comforts. The ice-making apparatus connected with the system supplies this commodity in sufficient quantity, and many an undesired landing for the purchase of ice and provisions is saved. The machine also saves a large amount of weight and space which the ice would require.

The expense of running the machine consists only of steam and oil and the labor of oiling it, and is small.

Fig. 134 shows the arrangement in elevation of the various parts of the Allen dense-air unit, comprising all the parts shown in Fig. 135.

Fig. 135 shows a plant using the Allen dense-air system, excluding the evaporator coils. These would, of course, be arranged in general as in the case of any direct expansion system.

The lettering of the various parts of the system corresponds to that in the description here given.

FIG. 134.

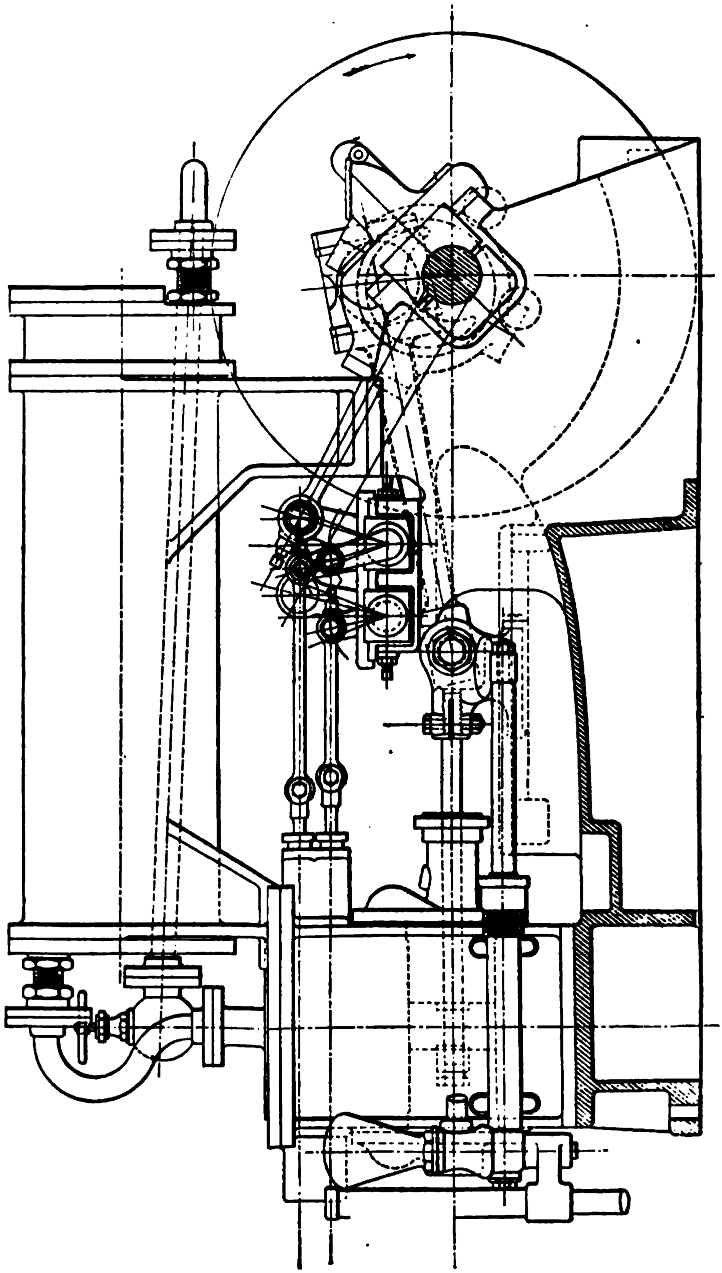
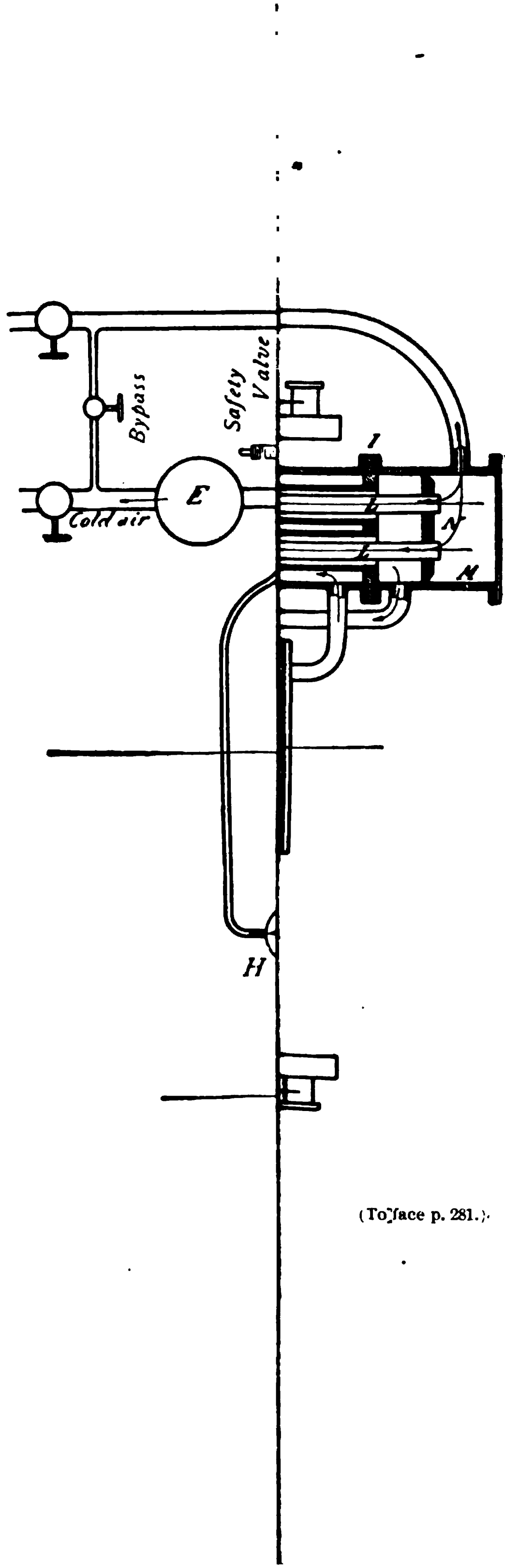


DIAGRAM SHOWING ARRANGEMENT IN ELEVATION. ALLEN DENSE-AIR ICE MACHINE.



(To face p. 281.)

DESCRIPTION OF MACHINE.

The Allen dense-air ice machine consists of the following eight parts:

A. The steam cylinder, which furnishes the power required by the whole apparatus.

B. The air-compressor cylinder, which compresses the air to about three times the entering pressure, which compression causes the air to heat considerably. The cylinder is, therefore, surrounded by a water jacket, in order to keep the piston packings from withering up.

C. A copper coil in a bath of water. The compressed hot air passing through the coil cools to the temperature of the cooling water.

CC. The return air cooler further cools this compressed air by means of the cold air returning from the meat house.

D. The expander cylinder, to which the cooled compressed air is admitted till it fills one-third of the volume of the cylinder. It is then shut off, and the piston continuing its passage to the end of the cylinder, the air is expanded to one-third the compressed tension (viz., to the same tension which it has when it enters the compressor). This expansion cools the air about as much as the compression heated it. Therefore, the air leaves this cylinder at a very low temperature. This air is then discharged into a well-insulated pipe, which conveys it to the point where the cold is to be utilized. There the pipe service is exposed, and the cold air apparently given out by radiation, etc., as heat is given out by a steam radiator, and after this utilization the air is returned to the machine, continually contained in pipes, and it enters the compressor for a new turn of compression, cooling and expansion. Before the expanded, refrigerated air goes into the conveying pipe, after leaving the expander, it passes through a trap E.

This trap gathers the lubricating oil used in the cylinder, and also a slight amount of snow, leaving the air very pure and clean when it runs through the pipes. The trap is provided with a heating pipe, and once in twelve or twenty-four hours this trap should be warmed up and the deposits drawn off by

the bottom cock. The machine is arranged, at the same time, to thaw out and blow into the trap any possible frozen deposits from the expander cylinder.

F. is a common plunger water-pump, which supplies the cooling water from trap H for the bath around the copper coil C and for the water jacket of the compressing cylinder B. The machine must be stopped if the supply should fail.

G. is a small supplementary air pump, which at starting primes the machine and the run of pipes with air to the requisite pressure, and which replaces losses of air from leaks through stuffing boxes and joints.

H. is a small trap, which extracts moisture from this newly supplied air, so as to have it enter the machine as dry as possible. The gathered water must be drawn off occasionally from the bottom pet-cocks.

CONDITIONS OF OPERATION.

The machine is constructed to use an air pressure of 60 pounds in the conveying and refrigerating pipes, and the air compressor compresses this to 210 pounds. If these pressures cannot be maintained, it is an indication that leaks have occurred, and the piston packings, and possibly the run of pipes, have to be examined. If the trap or any portion of the run of pipes is allowed to be choked by frozen oil or snow, or by closing of valves, the relation of the pressure will be disturbed. The cylinders have to be lubricated by the best quality of mineral lubricating oil, from which the paraffine has been removed by freezing.

The air-compressor valves are regular engine slide-valves, moved by eccentrics. The expander is also similar to a regular steam engine.

The piston packings in both of these are made of especially prepared leather.

Particular attention is to be drawn to the necessity of a constant good water supply, as the very life, as well as the efficiency of the machine, depends upon it.

PRINCIPLE AND METHOD OF APPLICATION.

The working principle of air ice machines is based on the creation of heat during the compression of air, and the creation of cold to an about equal amount during the expansion of the same. The machines, therefore, consist of an air compressor, which compresses the air and passes it into a cooling coil of pipe surrounded by circulating water. This removes the heat of compression and passes the compressed cooled air to the expander, a regular cut-off steam engine into which the air is admitted during a portion of the stroke of the piston. The admission is then cut off and the air in the cylinder is expanded as the piston proceeds to finish its stroke.

During this expansion the air is cooled to a very low temperature, and the return stroke of the piston pushes it out, and pipes convey it to the place which is to be cooled by it. It was usual to take air from the atmosphere and to refrigerate it in the above manner. A difficulty was experienced in the lightness of the air and the low capacity for cold, which was lost very quickly, and caused the machine to be large and cumbrous and expensive in steam, and necessitated it to be placed immediately adjacent to the cold room.

This again caused a special set of engineers to have charge of the same unless the cold room was placed adjoining the engine room. The American air ice machine (Allen dense-air ice machine) was constructed to overcome these difficulties, and does it in the following manner:

Instead of taking air from the atmosphere or from a cold room, and after refrigeration discharging it again into the room, the Allen machine keeps a charge of air of five atmospheres pressure (sixty pounds gauge pressure) contained in the machine and the conveying and refrigerating pipes, and uses the same over and over again, compressing it, cooling it in a copper coil surrounded by circulating water, expanding it in the expanding engine, and pushing it, when cold, through the conveying pipes to the cold room, where it also remains inside of pipes and does its refrigerating through the surfaces of the pipes. Then it passes back to repeat the performance.

As air of five atmospheres pressure contains five times as much cold as air of atmospheric pressure, and as it is conveyed in quite small pipes, the loss of temperature is small. This makes it possible to have the machine in the engine room under the care of the engineers while they are attending to their regular duty, and to lead the cold to any place which may be most advantageous to use as the meat house of the vessel. It can also be led to any place where ice-making can be attended to by one of the butchers or stewards along with his other work, and where the ice is easily taken care of.

The only part additional in the Allen dense-air ice machine over the old machine is the so-called primer pump, a simple small plunger pump which compresses the atmospheric air into the machine at the starting, and makes up the losses caused during the running by leakage from stuffing-boxes and pipe joints. There are also two traps which remove lubricating oil and water from the air and keep it pure while passing through the pipes.

As no absorbed water vapor has to be cooled from the vapor to the frozen state; and as the very much increased efficiency of the dense air causes this machine to be very much smaller than the old machine; and as the losses of temperature of the air are also very much smaller, a great reduction in steam expenditure results (fully fifty per cent.). No adjustment or manipulation of any part is required in order to produce best results. Whenever the steam sets the machine going it will produce its cold.

The temperature at which the air passes through the conveying pipes is practically 60° F. below zero.

VERTICAL ALLEN DENSE AIR ICE MACHINE.

Vertical machines operating on the same principles as the horizontal machines are made up in two sizes, for one-half ton and one ton, respectively, after the style shown in Figs. 135A and 135B.

Data as to the duty of these machines and floor space are given herewith:

Suitable easy daily work for the half-ton machine: Making 150 lbs. of ice and refrigerating 210 cubic feet of meat rooms to the freezing point and cooling 150 gallons of drinking water, or the equivalent differently distributed.

For the one-ton machine: Making 300 lbs. of ice and refrigerating 500 cubic feet of meat rooms to the freezing point and cooling 300 gallons of drinking water, or the equivalent differently distributed.

Floor room required: Half-ton machine, 3 feet x 3 feet 6 inches; one-ton machine, 3 feet 6 inches x 4 feet 6 inches.

TEST OF AN ALLEN DENSE AIR ICE MACHINE.

In a table given herewith are found results of a test on an Allen Dense Air Ice Machine on board the U. S. S. Virginia.

Auxiliary data bearing on the refrigerating effects produced and the apparatus used to produce the same are subjoined herewith.

DATA ON REFRIGERATING EFFECTS.

Capacity of rooms:

Admiral and captain, 365 cubic feet.

Junior and warrant officers, 257 cubic feet.

Crew, 1228 cubic feet.

Ward room officers, 501 cubic feet.

The rooms are of irregular shape.

Weight of ice blocks before melting out, 16 pounds.

Capacity of scuttle butts, each, 100 gallons.

DATA ON REFRIGERATING APPARATUS.

Capacity of plant, 3 tons.

Cylinder dimensions:

Steam, 10″ diameter, 14″ stroke.

Compressor, 9″ diameter, 14″ stroke.

Expander, $7\frac{1}{2}$ diameter, 14″ stroke.

The steam cylinder actually takes in about 50 pounds pressure and usual vacuum of auxiliary condenser.

The distribution of refrigerating effect is regulated at will by valves in the pipes.

TEST OF REFRIGERATING APPARATUS U. S. S. VIRGINIA. Oct. 10, 1905.

Time.	Pressure in Pounds.			Revolutions per Minute.	Temperatures F°.									
					Refrigerated Rooms.				Scuttle Butts.					
	Steam.	Compressor Cylinder.	Expander Cylinder.		Admiral and Captain.	Junior and Warrant Officers.	Crew.	Ward Room Officers.	Lower.	Upper.	Entry Chamber.	Sea Water.	Discharge Water.	Outer Atmosphere.
A. M. 9:00					74.5	75	75	78	69.5	69	80	69		67
10:00	145	200	55	92	64 5	64.5	70.5	68	69	69	77.5	69	75	67
11:00	153	252	73	101	49	52	58.5	53.5	65	68	77	69	75	70
M. 12:00	153	250	70	107	40	44	50	46	59	64	76	69	74	72
P. M. 1:00	142	250	70	102	32	37	43	39	49	57	75	69	74	76
2:00	150	255	70	108	26	31	37	33	42	50	75	69	74	74
3:00	155	250	70	100	22	26	33	30	37	44	74	69	74	74
3:30	143	250	70	94	19	24	31	28	24	41	73.5	69	74	74

Notes.—Test started at 9:10 a. m. with conditions as follows:

Ice cans 37° F.; ice-machine room 84° F.; steam pressure 140 pounds per square inch; R. P. M. 102.

Temperature of ice-machine room 84° to 100° F.

Opened air cock at 10:25 a. m., comp. cyl. 250 pounds per square inch, exp. cyl. 75 pounds per square inch.

Three cans (45 pounds) of ice at 12:00 m.

Full tank (135 pounds) of ice at 1:00 p. m.

Closed down at 8:30 p. m.

Test witnessed by B. B. Walsh,

CHAPTER XI.

THE AMMONIA ABSORPTION SYSTEM.

HENRY VOGT MACHINE CO.

THE ammonia absorption system of artificial refrigeration was introduced by F. Carré in 1861. Taking into consideration the numerous systems of refrigeration that have come and gone and the limited number of successful rivals, it is evident that the field of artificial refrigeration owes much to the absorption system. The general principles involved in the first machine by Carré are of course followed to-day, as there really is little chance for deviation in this respect. Alterations and improvements of details however have brought about a thorough transformation, so that the old can hardly be recognized in the new.

The Henry Vogt Machine Co. has established its right as the representative company for the absorption system of refrigeration by a record of constant improvements as suggested by experience over a period of a dozen years, inaugurated by the erection of a machine that was a success at the start.

The descriptions and references given herewith apply to the leading features of the system manufactured by these people.

THE GENERATOR OR RETORT.

The generator or retort is the part of the system in which the separation of the anhydrous ammonia from the aqua ammonia takes place. This separation is brought about by heat. In the generator to be described, the heat for this separation is applied by means of steam pipes. See Fig. 138.

In general the apparatus seems to consist of a bank of horizontal cylindrical tubes of considerable size, the number of tubes in the bank differing in the different-sized machines,

surmounted at one end by a high column or tower. The bank

FIG. 136.

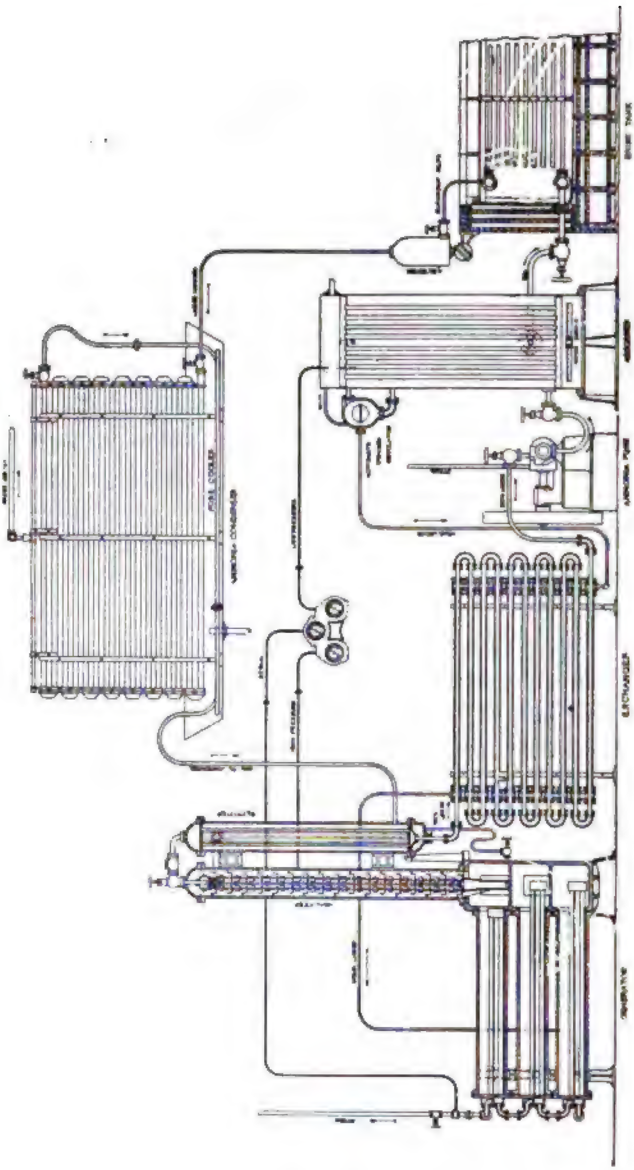


DIAGRAM OF ABSORPTION SYSTEM—GENERATING PLANT.

of horizontal tubes with the base of the tower constitutes the

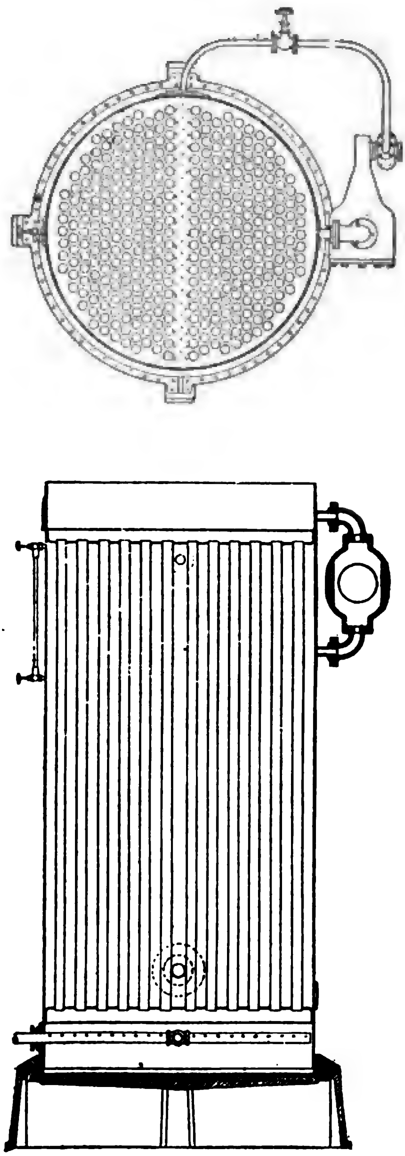
generator proper. The cylindrical tubes referred to are made of extra grade of wrought-iron lap-welded pipes. These tubes receive the aqua ammonia from which the anhydrous ammonia is driven off. The heating surface within these cylindrical chambers consists of from seven to eighteen lengths of one and one-quarter inch pipe. These lengths of pipe for heating extend completely through the cylinders, passing through the heads and projecting outside. The pipes are fitted to the passages in the heads by rolling so as to make them tight. At the back end those of each pair fit into return castings. By this arrangement, few joints or connections in the steam pipe are exposed to the ammonia and the pipes can be readily removed and renewed.

The upper part of the stand-pipe contains the analyzer, with a series of horizontal separating pans. The lower part consists of a series of chambers, one for each horizontal tube, and consequently one above the other, into which the tubes, respectively open. These chambers have connections to the tower for the passage of gas.

The top of the stand-pipe serves as the inlet for the aqua ammonia and for the outlet for the anhydrous ammonia gas. The aqua ammonia is delivered to the separating pans. From the pans it falls to the upper chamber in the base of the tower. From this chamber the aqua ammonia passes to the uppermost of the horizontal cylindrical tubes into which it opens. Being subject to the heat in the steam pipes in this tube, ammonia gas will be driven off which will find its way back to the top of the tower and out to the condenser proper. What has been outlined for this uppermost cylinder is still further extended in the lower chambers to which the aqua ammonia is admitted in succession, the difference being one of degree, the ammonia becoming of course continually weaker until its condition is such when it arrives at the lowest tube that it is classed as weak liquor. In a generator of four cylinders the aqua ammonia drops from the tower to the uppermost chamber as mentioned and passes from the chamber to the outer end of the cylinder. By an outside connection, it passes

thence to the outer end of the second cylinder from the top.

Fig. 137.



ABSORBER.

Thence it passes to the chamber connected to the second tube. Passing to the next lower chamber, it flows along the outer end of the third tube. From this tube it passes by an outside connection to the outer end of the fourth tube. Passing along this last tube, it enters the lowest chamber, from which it leaves the generator.

The gas is in each case passed through the chambers up into the stand-pipe. Each horizontal cylinder has its own heating surface, all being connected in series.

The desired result is accomplished with very little steam pressure, in some cases the pressure used being 45 pounds per square inch.

The generators are tested at 500 pounds pressure.

THE RECTIFIER.

The rectifier is for the purpose of rendering the ammonia anhydrous by the removal of water or weak liquid. A network of vertical tubes carries the rich

liquid en route to the analyzer. The surrounding chamber contains the ammonia gas en route to the condenser together with what liquid is carried over with it. This liquid falls to the bottom of the rectifier, whence it may be drawn off to the generator.

THE ABSORBER.

The absorber, see Fig. 137, is made of extra-quality boiler steel, and contains a sufficient number of tubes made from special charcoal iron. The arrangement of the tubes is such that they can be cleaned while the machine is in operation. The tubes are especially arranged to obtain an efficient cooling surface, the water entering below and discharging at the top.

AUTOMATIC REGULATOR.

An especially valuable adjunct to the absorber is the automatic ammonia regulator.

The function of this apparatus is to ensure a uniform flow of the weak liquor to the absorber, and accordingly to render possible the automatic operation of the absorber and incidentally of the entire system.

THE EQUALIZER.

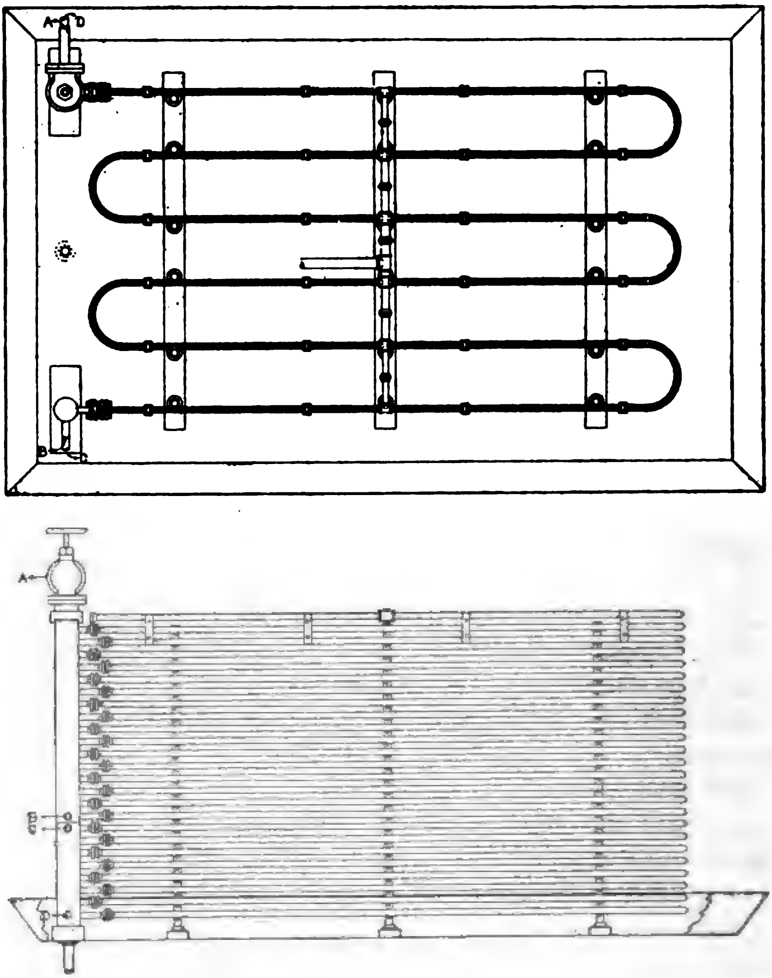
The equalizer in an absorption plant is an ingenious arrangement for economizing by facilitating an advantageous transfer of heat from the weak liquor to the strong aqua ammonia.

The weak liquor is on its way from the generator, where it has been subjected to heat, to the weak liquor tank, en route to the absorber where it is wanted cold, while the strong liquor is en route from the absorber, where it is comparatively cold, to the generator where it is to be subjected to heat. The temperature of the weak liquor as it enters the equalizer may be about 281° Fahrenheit, while that of the strong liquor may be about 80° Fahrenheit. It is evident that there is opportunity here for a gain in effecting a transfer of heat as outlined.

The method in which this idea is applied is certainly ideal.

It consists in having the pipes for the two liquids arranged one inside of the other for the straight lengths. For the return or end connections special fittings are used. The inner

FIG. 138.



ATMOSPHERIC CONDENSER, ZIGZAG COILS.

smaller tubes pass outside and are connected by semi-circular return bands, while the passages for connecting the interior of the outer tubes are directly across in a straight line. A view

of the equalizer described is shown in Fig. 63, Part I, Chapter XVII.

The equalizer is generally located near the generator and parallel to the same.

THE AMMONIA CONDENSER.

The ammonia condenser may be either of the submerged type or the atmospheric type. The latter type is recommended where the supply of water is limited.

The submerged condenser is made of coils of extra-heavy pipe submerged in a steel tank and connected with a flange connection of special design to headers.

The atmospheric condenser is made of extra-heavy pipe, made into zigzag coils of single length to a coil. The ends are connected to a wrought-iron header by flange connections. These flanges are made tight by means of a recessed joint with a gasket. The coils are so shaped and arranged that they can be readily cleaned while in operation.

The condenser is placed in a pan of wrought iron, which collects all the water. From this pan the water passes to the weak liquor tank. Fig. 138.

THE WEAK LIQUOR COOLER.

The weak liquor cooler is used for the purpose of cooling the weak liquor passing from the generator and equalizer to the absorber. It is made either of the atmospheric or submerged pattern.

It is generally located just below the ammonia condenser and designed to utilize the water that has been used for the cooling in the same. In this way the weak liquor may be sufficiently cooled to be admitted to the absorber with good economy and without especial inconvenience or care.

THE STANDARD AMMONIA PUMP.

The ammonia pump is the only mechanically operating part of the plant, outside of the boiler room, where the usual feed pump may be found: Fig. 139.

The office of the pump is of course to pump the strong aqua ammonia from the absorber to the generator. An ordinary pump would not do for this purpose, as special precautions

FIG. 139.

FIFTY-TON STANDARD AMMONIA PUMP.

must be taken to prevent loss of ammonia. The usual speed is from twenty to twenty-four revolutions per minute for the pump designed for a fifty-ton ice plant.

DESCRIPTION OF AN ICE PLANT.

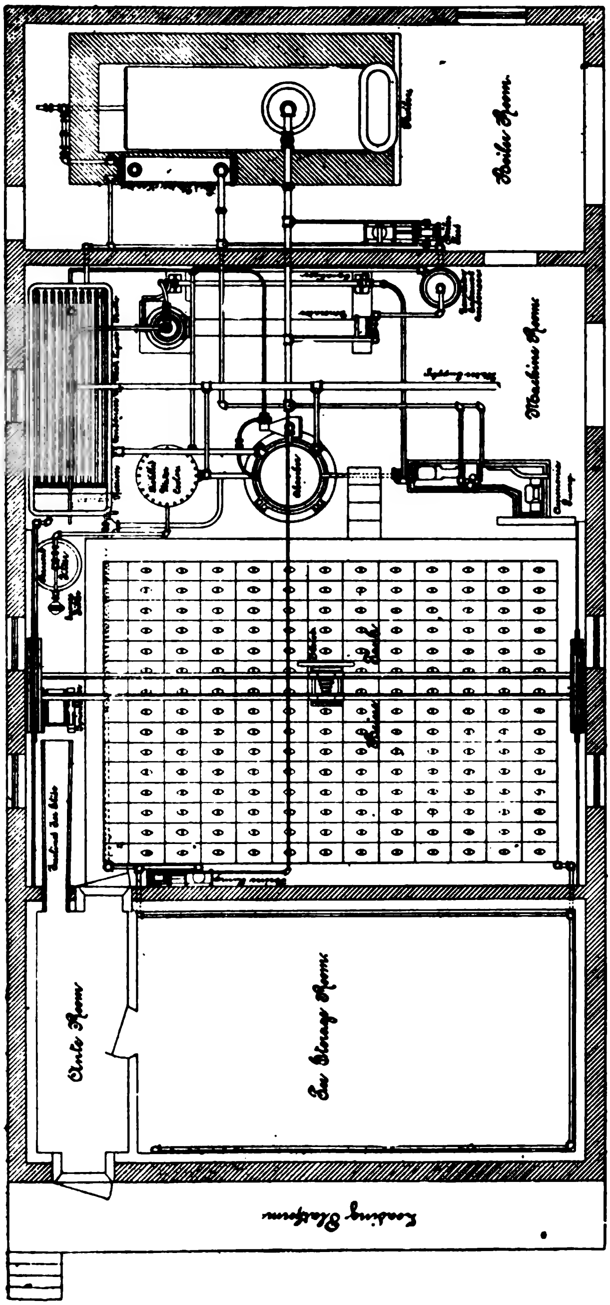
An artificial ice plant operated under the absorption system will now be briefly described. (See Figs. 140 and 141.)

The principal apparatus would include a steam boiler, generator, exhaust steam feed-water heater, distilled water cooler and storage tank, charcoal filter, freezing cans and freezing or brine tank, thawing apparatus, equalizer, ammonia condenser, expansion valve, expansion coils, absorber, ammonia pump, and feed pump.

The mediums used are water, brine, steam and ammonia.

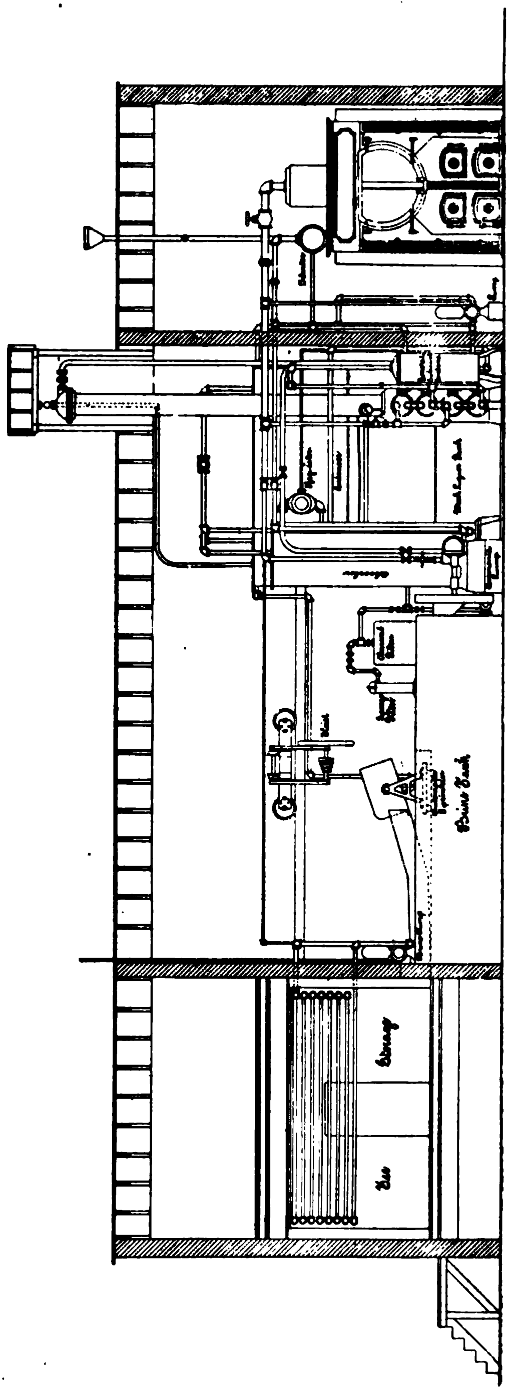
Brine is used in the freezing tank or brine tank as a medium for transferring the heat from the freezing cans containing the water to be frozen to the expansion coils.

FIG. 140.



GROUND PLAN FOR ICE PLANT. ABSORPTION SYSTEM.

FIG. 141.



SIDE ELEVATION FOR ICE PLANT.

One branch from the water supply carries water to the upper part of the distilled water cooler, in which the distilled water is cooled to a temperature of about 90° Fahrenheit. The water used for cooling is discharged into the sewer.

Another branch of water passes to the ammonia condenser for cooling purposes, from which it passes to the weak liquor tank for further duty in this line, passing from this to the sewer.

Another branch of water is taken from the mains by the feed pump and forced through a feed-water heater, heated by exhaust steam from the generator heating coils, to the boiler.

The steam from the boiler passes to the heating coils of the generator, thence through the feed-water heater to the upper part of the distilled water tank, where it is cooled by water as stated to about 90° Fahrenheit. From the upper part of the distilled water cooler it is passed to the lower part, where it is reduced to a low temperature by coils with the return gas from the expansion coils on the way to the absorber. From the distilled water cooler the condensed steam is passed through a charcoal filter to the distributing pipes for supplying the freezing cans. The cans with ice are removed by a convenient hoist to an automatic thawing apparatus for releasing the ice from the can. The ice when released slides down a slide to a point convenient for the handling of the ice for shipment or storage.

As the steam used in the generator is not sufficient to supply the distilled water required for the ice, live steam is fed directly from the boiler to the distilled water cooler to make up for the deficiency.

The course of the ammonia may be conveniently followed by beginning with the strong aqua ammonia formed in the absorber by the union of the weak liquor and the anhydrous ammonia or ammonia gas. From the absorber the aqua ammonia is pumped through the equalizer to the upper part of the stand-pipe of the generator. The weak liquor passes from the lower part of the generator through the equalizer to the weak liquor tank. From this the weak liquor is admitted to

the absorber. An automatic regulator used for regulating the flow of weak liquor to the absorber is an important adjunct to the system. The anhydrous ammonia produced in the generator passes out at the top of the stand-pipe of the generator to the ammonia condenser, where it is condensed to the liquid form. From the ammonia condenser the liquid anhydrous ammonia is admitted by an expansion valve to the expansion coils, where it assumes the form of gas. These coils are properly arranged in the brine tank for cooling the brine, and thus indirectly freezing the water in the freezing cans.

From the expansion coils the anhydrous ammonia, now in the form of gas, passes through a cooling coil in the lower part of the distilled water cooler to a final completion of the cycle by entering the absorber, where it is again united with the weak liquor to form strong aqua ammonia.

The simplicity of the method is certainly largely due to the fact that no oil is used in the system, so that the steam may be passed from the generator, where it does its work, directly to the cooler without extensive cleansing apparatus.

CHAPTER XII.

THE AMMONIA ABSORPTION SYSTEM.

RANSOMES & RAPIER SYSTEM.

THE apparatus used in this system has some unusual features in the structural details. The machine is almost exclusively constructed of steel, and consists of five cylindrical vessels almost exactly alike externally as shown in Fig. 142 and similar internally. Besides these, there are the small circulating pump and the brine cooler, such as may be employed in any system.

The novelty lies in the method of construction of the cylinders, both externally and internally.

METHOD OF CONSTRUCTION.

A, Fig. 143, is a wrought iron cylinder having covers *B* and *C* bolted on. A cast iron header *D* having a cover *E* is bolted on to the cover *B*. Wrought iron tubes *F* closed at one end are screwed into the cover *B*, and supported at their other ends by a tube plate *G*. Small tubes *H* and *K* are screwed into the header *D*, and pass down the center of the tubes *F* almost to their closed ends.

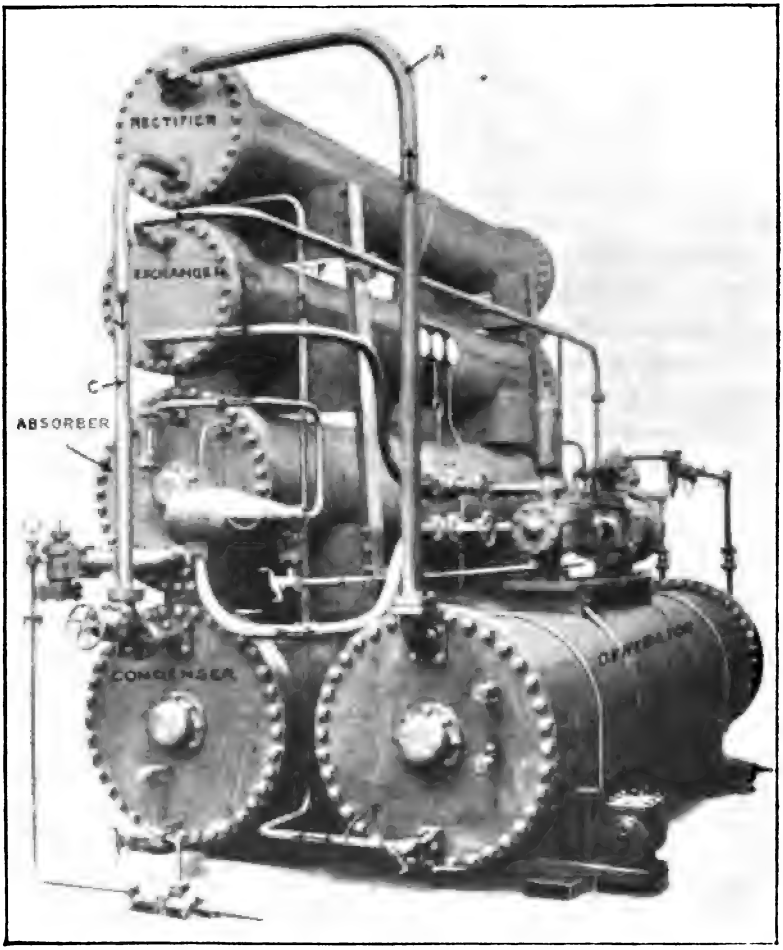
The condenser, absorber, exchanger and rectifier are all constructed in this way. The generator is also similarly constructed, but the tubes *F* are only in the lower half of the cylinder *A*.

In the exchanger there are two sets of tubes, one set being used for further cooling the weak liquor before it enters the absorber.

In the generator, steam passes in the tubes *F*, and in the

condenser, absorber, exchanger and rectifier, the condensing water passes through these tubes.

FIG. 142.



100-TON AMMONIA ABSORPTION REFRIGERATING MACHINE.

In all cases the ammonia pressure is in the cylinder *A* and outside the tubes *F*.

The ammonia pump is direct acting steam driven. It has

an extra long stuffing-box so arranged that any leakage from the first stuffing-box is carried back into the suction. The valves are of vulcanite and easily renewable.

It should be borne in mind that this pump is only required for pumping ammonia liquor, and not ammonia gas, as in the compression machine. Only a very small pump is required, being about $\frac{1}{50}$ of the capacity required for a compression machine.

FIG. 143.

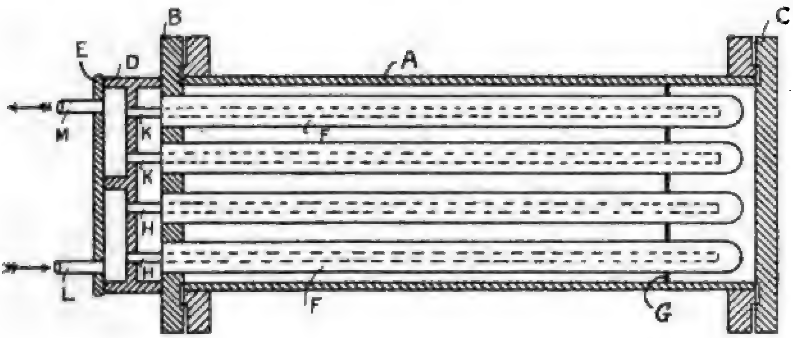


DIAGRAM OF CONSTRUCTION OF CYLINDRICAL CHAMBERS.

The gauge fittings for showing the level of the ammonia in the different vessels are made to close automatically in the event of a glass breaking.

DIAGRAM OF OPERATION.

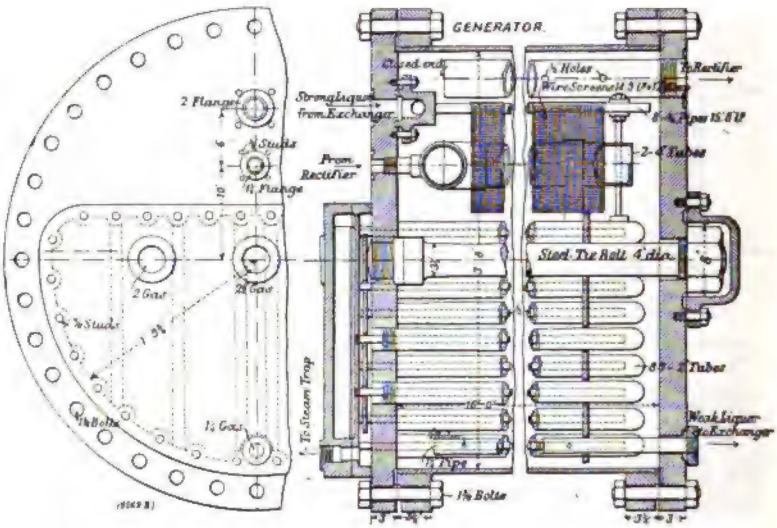
The diagram of operations is shown in Fig. 1, and was explained in detail in Part I, Chapter II, to which attention is called for this important feature.

DETAILS OF APPARATUS.

In Fig. 142 the cylinder in the foreground is the generator, and the other cylinders, from the top downwards, are successively the rectifier, exchanger, absorber, and condenser. A view of one end of the generator and a vertical section are given in Fig. 144. Steam enters through the three orifices on the centre line of the left-hand cover, and passes down the small tubes to the other end of the cylinder. It returns

along the annular spaces between the small and the large tubes, becoming condensed in its passage, and escapes as water through a steam-trap. The thin plate shown round the necks of the small tubes is for the purpose of keeping them properly spaced and if withdrawn for any purpose, to facilitate their replacement. The cylinder itself is of welded steel, 16 ft. long, 3 ft. 8 in. in diameter, and $\frac{9}{16}$ in. thick. Flanges are screwed on at each end, and the covers, each of which is a

FIG. 144.



END VIEW OF GENERATOR. VERTICAL SECTION OF GENERATOR.

rolled steel plate, machined all over, and 3 in. thick, are bolted on. A $3\frac{1}{2}$-in. stay-bolt connects the covers, the external nut being covered by a cap to prevent leakage of ammonia.

The strong liquor from the exchanger flows into eight longitudinal pipes in the upper part of the cylinder, and runs down over surfaces of wire gauze, being thus spread out over a very large surface in a thin film. The ammonia gas mixed with vapor ascending in the generator passes over this surface, and an interchange of heat takes place, a large part of the gas in the strong liquor being thus evaporated, and at the same time some of the vapor in the ascending gas condensed.

The process, therefore, which in other absorption machines takes place in a separate vessel called an "analyser," in this machine is accomplished in the generator itself. The gas is collected by the large pipe in the highest part of the cylinder. The construction of the absorber is similar to that of the generator. The circulating tubes, however, carry cold water in place of steam. The external tubes are screwed and expanded into the thick tube-plate, and are further locked by a screwed ferrule run down on to a lead ring. The passage of the weak liquor into the absorber is controlled by an automatic regulator, consisting of a lever float, which rotates a a cylindrical valve as it rises and falls. The liquor overflows from the absorber into the float-chamber, from which the pump suction is taken, the float-chamber being below the level required in the absorber. As soon as the liquor overflows faster than the pump takes it away, the float-chamber fills, the valve closes, and shuts off the supply of weak liquor. The variation of level in the absorber is thus very slight, being only a fraction of the variation in level, or travel, of the float.

COMPENSATING VALVE FOR BRINE PUMP.

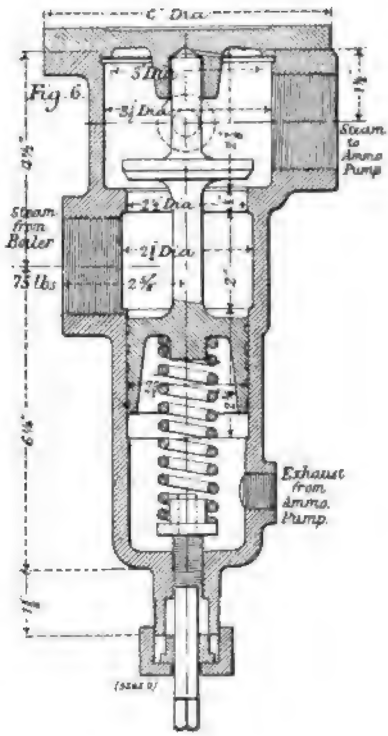
The exhaust steam from the ammonia pump is passed into the generator, hence the back pressure on the steam end of the pump will vary from 0—as, for instance, in starting the machine—to 45 lb. By using the compensating valve, shown in Fig. 145, the effective steam pressure on the pump is constant, whatever the back pressure. As the exhaust pressure rises it acts on the piston and helps the spring to hold the valve open, so that the steam pressure to the pump rises exactly in proportion. The speed of the pump is therefore constant under all conditions. The difference between the high pressure and the exhaust is regulated by the hand wheel provided.

OPERATIVE RESULTS AND TESTS.

The pressure in the absorber when the plant is used for cooling brine to 15° F. does not exceed 15 lb. per square inch.

The pressure of both the ammonia gas in the generator and of the steam for driving it out of solution depend principally upon the temperature of the cooling water which can be obtained. With cooling water entering at 60° F., and leaving at 100° F., the steam pressure required is 45 lb., and the resulting generator pressure 150 lb. In the tropics, where the

FIG. 145.



COMPENSATING VALVE—SECTIONAL VIEW.
FOR REGULATING STEAM PRESSURE FOR AMMONIA PUMP.

cooling water might enter at 90° F. and leave at 115° F., 60 lb. of steam would be used, and the generator would then work at 200 lb.

The total steam consumption of the machine, including that required by the circulating pumps, measured on a five hours' test, amounted to only 2200 lb. per hour at a boiler pressure

of 65 lb. This is equivalent to 22 lb. of steam per ton of refrigeration, and is an exceptionally low figure considering the low brine temperature, and we doubt if this efficiency has ever been equaled by a compressor machine.

The machine illustrated has been built under Cracknell's patents, for the Broxburn Oil Company, who already have four 60-ton machines, the largest size hitherto made in Great Britain. It is to be used for cooling brine to —10° F., the temperature required for refining paraffin by a method of freezing out the wax, patented by Mr. Henderson, the works managing director.

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CHAPTER XIII.

THE AMMONIA ABSORPTION SYSTEM.

THE POLAR REFRIGERATING MACHINE.

The characteristic feature of the Polar absorption apparatus produced by the Isbell-Porter Company, is the use of the shell type of construction, including the condenser, absorber, and brine cooler, which are of the vertical type. The apparatus is shown in diagram Fig. 146.

DESCRIPTION OF THE MACHINE.

The Polar refrigerating machine consists of a still for evaporating dry ammonia gas under pressure; a condenser for liquefying the gas; a brine cooler or expansion coil in which the liquid ammonia expands into a gas; an absorber in which the gas is absorbed by water from the still, and a pump which returns the water from the absorber to the still.

The generator, analyzer, rectifier and heater, form the still. The charge of ammonia is placed in the generator and heated by steam passed through coils. The heat drives the ammonia vapor out of solution under pressure, and it passes upward through the analyzer, where most of the water held in suspension is removed by a series of baffle plates. The vapor passes to the rectifier, where the remaining water is condensed. The anhydrous vapor then passes to the condenser, where it is liquefied on the surface of coils through which water is circulated. The liquid ammonia falls to the bottom of the condenser, which serves as a receiver, and is fed in regulated quantities through an expansion cock to the brine cooler. The drop in pressure allows the liquid ammonia to absorb heat and expand about coils through which brine is circulated. The other features will be readily understood from the previ-

Fig. 146.

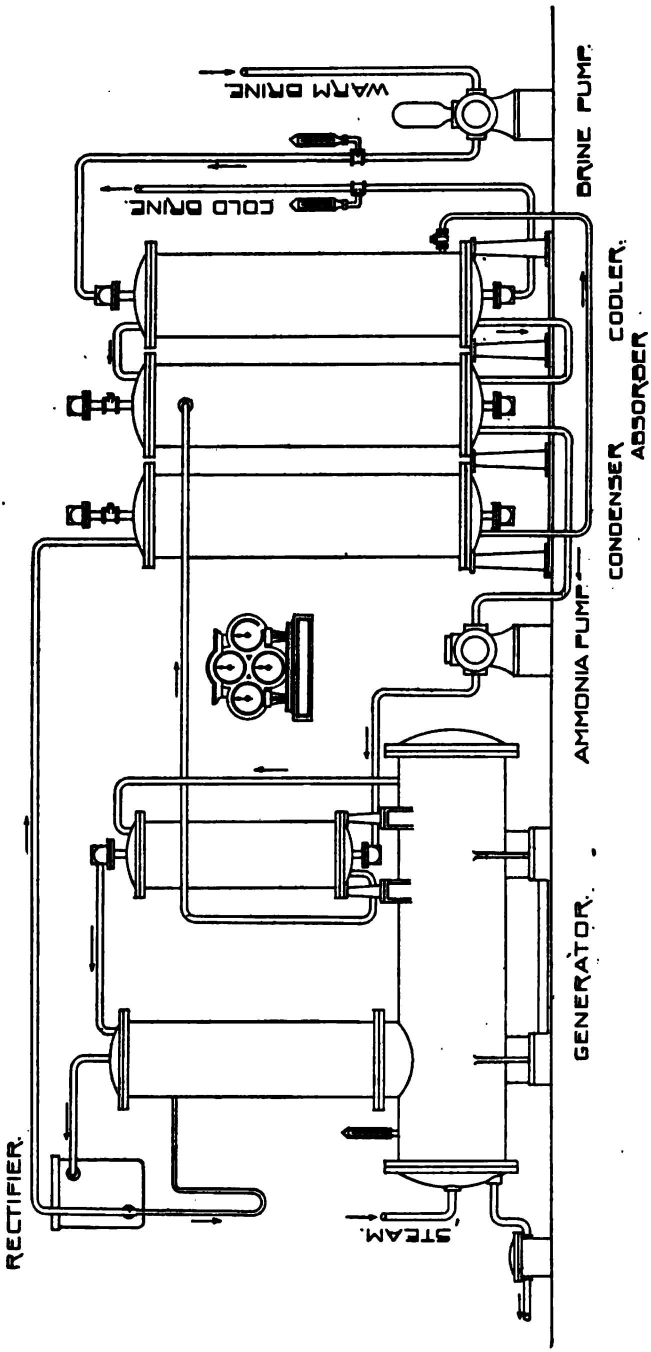
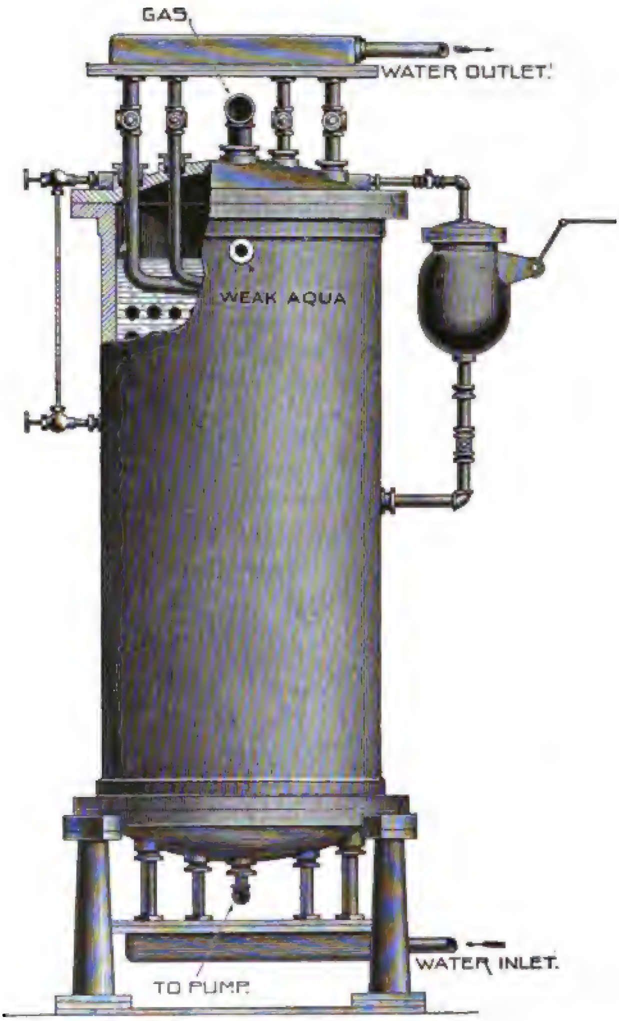


DIAGRAM OF THE POLAR MACHINE, ARRANGED FOR BRINE CIRCULATION.

ous references to the absorption system and inspection of the illustrations.

FIG. 147



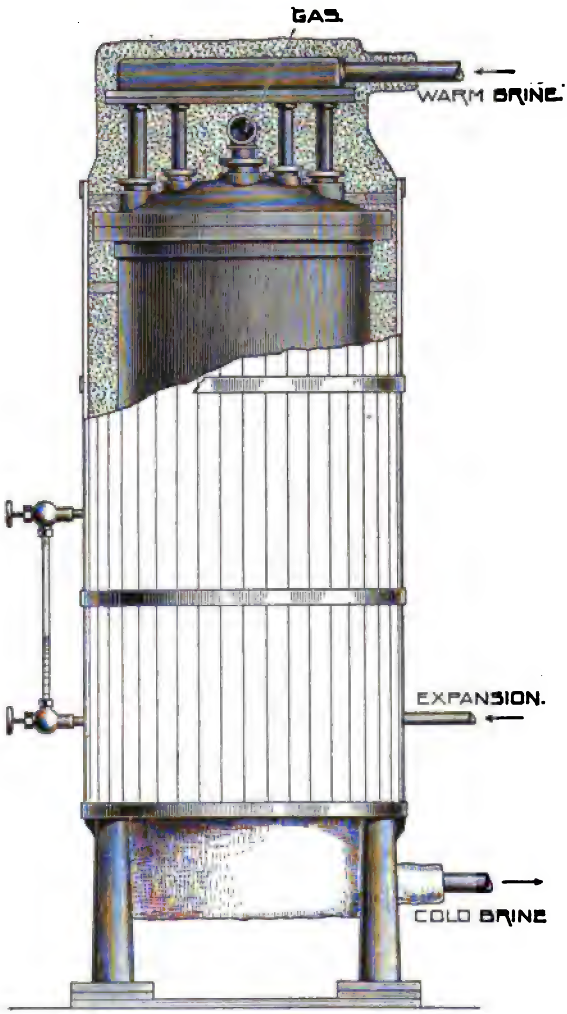
THE POLAR ABSORBER.

A sectional view of generator, analyzer and heater is shown in Fig. 62, Part I.

CONSTRUCTION OF THE MACHINE.

The vessels are all made with heavy cast-iron shells and

FIG. 148.



THE POLAR BRINE COOLER.

heads. The coils are wound concentrically, project through stuffiing-boxes in the heads, and are manifolded outside of

the shells. The generator and rectifier have oval coils. All coils are welded throughout and made of strictly wrought-iron lap welded, extra heavy pipe. All openings for connections are reinforced with glands, and all pipes, valves and fittings, are extra heavy to guard against leakage. All vessels are provided with liquid level gauges and pressure gauges of approved design. All machines are equipped with pumps controlled by automatic governors, for the aqua ammonia.

The condenser is shown in Fig. 35, page 85. The absorber and brine cooler are shown respectively in Fig. 147 and Fig. 148.

OPERATION OF THE MACHINE.

The skill required to run the Polar machine is such as is needed to run a boiler. The engineer has under his control, in addition to the expansion valve, a valve to regulate the supply of weak aqua to the absorber. The valves for the steam to the generator and the ammonia pump are controlled by automatic regulators, and adjust themselves for a given position of the expansion valve and the weak aqua valve. The machine has so few moving parts, and these are so directly under the engineer's eye, that it can be operated continuously twenty-four hours a day for an entire season without undue wear and tear.

EFFICIENCY.

The machine receives its power directly from the latent heat of steam without the wasteful loss experienced in a steam engine. It returns the condensed steam to the boiler at a temperature much above that of the average feedwater. If the machine is properly insulated and supplied with a large heater, and utilizes in the generator the exhaust steam from the pumps, it surpasses in efficiency the most approved form of steam engine that may be used in driving a compressor.

CHAPTER XIV.

THE AMMONIA ABSORPTION SYSTEM.

TEST OF CARBONDALE ICE PLANT.

The elements of the absorption system produced by the Carbondale Machine Company are for the most part of the shell type. With all that has been said about types of apparatus and details of processes, we will venture to omit references to their features in the present case, and instead will present some data on an ice-making plant employing apparatus of their construction, including results of test, which will probably be found to be fully as interesting and instructive.

DETAILS OF PLANT.

The plant referred to was a small plate ice-making plant with a nominal rating of 10 tons. The results of the test showed that this plant produced 146 tons of ice per day for seven days at a rate of 1404 tons of ice per day per ton of coal.

The machinery was installed in a room 13′x46.5′ in plan, at a rate of 60.5 square feet per ton of nominal ice-making capacity.

The entire ice plant is housed in a structure consisting of a main portion 32x79.5 feet in plan, containing the machinery, freezing and ice stores, and extension 14x25 feet on one end occupied as a boiler-room, and a small extension at the other end for the office. The building is entirely of frame construction, the main members consisting of 6x6-inch posts on 13½-foot centers, which support timber roof trusses. It is sheathed with clapboards on the sides, and has a tar and gravel roof. The tank and machinery rooms occupy 47 feet of the total length, with an inside width of 30 feet. The freezing tank takes up 18 feet of the width, and is spanned by a 4-ton hoist-

ing crane, which travels from end to end of the room to deliver the plates of ice to the ice storage rooms beyond. To carry the inner end of the crane, an interior row of 6x6-inch posts extends through the room, leaving a clear width of 13 feet for the machinery department. The crane rails are carried by longitudinal 6x10-inch yellow pine stringers resting on brackets fixed to the posts. The lower cords of the roof trusses are 24 feet above the floor line, leaving two feet clearance above the top of the crane, and allowing the plates of ice, which are 8½ feet deep, to be lifted clear of the tank. The floors are of concrete.

The storage rooms comprise a 10x30-foot temporary storage, into which the ice is discharged from the tank or freezing room, and a 20x30-foot ice storage 29 feet high in the clear, with a capacity of 325 tons. The temporary storage extends under the tipping table of the tank room, with a consequent saving of space, and opens upon a loading platform outside, where the ice is delivered to the wagons through a self-closing door. The temporary storage serves as an ante-room between the outside atmosphere and the main storehouse. The insulation of these rooms is 10 inches thick, and consists mainly of 1-inch outside clapboards, 2 courses of paper, 1-inch sheathing, 6 inches of mill chips, 1-inch sheathing, 2 courses of paper, and 1-inch sheathing.

The boiler is a 60-horsepower tubular boiler built by the Atlas Engine Works, Indianapolis. The usual steam pressure carried is 80 pounds, but at the back of the boiler, at a point where the hot gases can strike it, is a Foster steam superheater, provided in order that a minimum amount of moisture will be expelled in the exhaust from the steam engine.

The steam is conducted from the boiler in a 2-inch pipe, supplying a 1½-inch line to the engine, which is 7x9-inch 12-horsepower Porter slide valve engine, and a 1-inch line which is provided with a reducing valve to deliver live steam to the generator when necessary.

The following triplex pumps are belted to a jack shaft, connected to the engine: A 2½x6-inch ammonia pump to force

the ammonia liquor from the absorber to the generator; a water pump for lifting water from a well on the premises, 50 feet deep; an 8x6-inch air agitator, which is an air compressor for discharging air through the water to be frozen in order to prevent the collection of air-bubbles, which lend an opaqueness to the ice; a $1\frac{1}{4}$x$2\frac{1}{2}$-inch pump for boiler-feeding; and a similar sized pump, which can be interchanged with boiler feed-pump, for circulating warm brine through the coils distributed over the ends and bottom of the freezing plates for melting the ice away from the plates when freezing has been completed.

The freezing machinery has a nominal rating of 10 tons, but an actual commercial capacity of 12 tons. The type of generator is that having a horizontal cylindrical chamber in which the steam coils are placed and two vertical cylinders rising from the top, the latter mainly for effecting an exchange of heat between the inflowing and outflowing liquors and for preventing, so far as possible, the carrying-off of any water with the gas. The usual overhead rectifier for more effectively removing the moisture from the hot ammonia gas by condensation, the condenser for liquefying the high-pressure ammonia gas, and the absorber for receiving the low-pressure ammonia gas after it has absorbed heat from the water in the forecooler and in the freezing tank during the change of state are provided. The well-pump is piped to deliver to the condenser only. The city water being pure is delivered by its own pressure into the forecooler, which is a tank where the water may be cooled before being turned into the freezing tank. The water from the condenser is passed in part through the rectifier and in part through the absorber, and is then discharged to waste, except what goes to the thaw tank. From this tank the warm water is taken by the thaw-pump, as explained. The water from the well may also be delivered to an injector for feeding the boiler or to a receiver from which the boiler feed-pump draws its supply. Very little water is required in this way, however, as the exhaust steam that is condensed in the generator is trapped to the receiver, and furnishes nearly

the full supply of water needed, the additional amount being required to make good any losses by leakage.

OPERATING DETAILS AND TEST.

It has been found that by a proper adjustment of the valve on the engine the generator requires just the amount of steam that the small engine uses when running the pumps. During the test, to which more detailed reference will be made, the temperature of the exhaust was about 255.7 degrees, which corresponds to a back pressure on the engine of about 33 pounds absolute.

The temperature of the water fed to the boiler during the test was about 220 degrees, which, of course, means that it is under pressure. The valve in the engine free exhaust was closed and did not leak, or at least no trace of steam could be seen escaping. A Cochrane oil separator made by the Harrison Safety Boiler works is provided in the exhaust line from the engine to the generator.

RESULTS OF TEST.

Ice Production:

Number of plates, 14.
Number of cakes of ice per plate, 2.
Number of cakes of ice harvested each time, 4.
Number of harvests, 8.
Time of test, 1 week, 7 days.
Dimensions of cake 8′2″×15′×11″ thick.
Weight of cake, 3.2 tons.
Weight of each harvest, 12.8 tons.
Weight of total harvested, 102.4 tons.
Rate per day, 1462 tons.

Coal Consumption.

Total . . . . $\begin{cases} \text{14.589 pounds.} \\ \text{7.29 tons.} \end{cases}$

Per ton of ice, 14.04 tons.

PART III.

STRUCTURAL INSULATION.

PERFECTION in insulation implies a condition in which there is no transfer of heat between bodies of different temperature. Such a condition is ideal and is impossible of attainment. Accordingly, however much we may improve and progress, we have this fact staring us in the face. We may judge our success from the standpoint of this actual condition and use the same as the goal towards which we may endeavor to approach, knowing all the time that we will never fully reach the same.

Imperfect insulation means loss of refrigerating effect, and consequent drain on the coal pile. Adding to the outlay for improvements of insulation results in reduction of operating expenses. This implies a contest between first cost of construction and interest charges and cost of refrigerating machinery and of the operation of the same. The result is a compromise, to be determined in each individual case from the conditions at hand.

In practice the best results obtained involve a loss of about one-half of the entire refrigerating effect through the walls, and in most cases the loss is considerably in excess of this.

Between the impossible extreme of perfect insulation and the absurd extreme of no insulation we may still recognize the grades of good and poor.

There is no excuse for poor insulation, for it cannot be defended from any standpoint.

Good insulation is the kind that pays for itself in the saving in operating expenses and maintenance.

The difficulty is to know what is good insulation, because

of the number of different standpoints from which it may be judged.

Permanence of conditions is a feature frequently not properly looked to. A promising beginning may be followed by little short of failure, as evidenced by an unexpected and mysterious drain upon the machinery. The explanation of this may be looked for in changes brought about by displacement of woodwork by the pressure of the packing material, or the settling of improperly placed packing.

The efficiency of insulation depends both upon the materials employed and the method in which they are employed. The effects obtainable by good insulating materials may be offset by a poor arrangement of the same, while good results may be attained with comparatively poor materials by a judicious arrangement.

It is evident that the problem involves a choice of materials and due consideration of details of construction. In general, the practice involves a composite structure consisting of different materials combined in accordance with some carefully designed plan. Elaborate formulæ may be used for determining the insulating value of a given combination, but the most satisfactory method is to actually determine the insulating value of the particular structure by experiment, or to assign a value for the same, based upon values that have been determined for similar structures.

At one time about the only guide in regard to insulation was such information as was offered by manufacturers of refrigerating apparatus. A number of such plans are given in the following pages. Recently reliable data have appeared, as a result of elaborate and costly experimental work, so that the problem can be handled with the possibility of determining beforehand with reasonable certainty the results that may be expected.

A few fundamental suggestions may be mentioned.

No material should be used in the insulating structure that has an odor that might be imparted to provisions in storage. It is important to bear in mind that pine is excluded from the list of available materials on this account.

The material should be waterproof and not liable to absorb moisture. As this is hardly attainable, the next best thing to do is to house it in with waterproof material, such as waterproof paper or by use of pitch.

It should not have a tendency to disintegrate, or rot, or to settle so as to leave vacant spaces. This excludes sawdust and calls for judgment in packing.

It should be cheap and readily handled in application. However, as other features need also to be considered, the cheapest in first cost may be the dearest in the end. A material that is cheap and good as a filler is mill shavings. Mineral wool is about in the same class. Cork, either sheet or granulated, is good, though more expensive. Sheets of felt and quilting, used for deadening sound in walls of dwellings, are generally durable and reliable.

It is desirable that the material should be fire-proof. About the only material that has this quality is mineral wool.

After all, the best insulation is air spacing, excepting, of course, a vacuum, which is out of the question. This does not mean the old-fashioned open air space, but small air cells, which form the true insulating features of the different porous materials and the small air spaces that are obtained by using such materials as fillers in otherwise open spaces.

A table of insulating values of various materials is given on page 98, Part I, Chapter X. Other data are given in the table herewith :

RELATIVE VALUE AS NON-CONDUCTORS OF HEAT.

(Chas. E. Emery.)

Non-Conductor.	Value.	Non-Conductor.	Value.
Wood Felt	1.000	Loam, dry and open	.550
Mineral Wood No. 2	.832	Slacked Lime	.480
Mineral Wood with tar	.715	Gas-House Carbon	.470
Saw Dust	.680	Asbestos	.363
Mineral Wood No. 1	.676	Coal Ashes	.345
Charcoal	.632	Coke, in lumps	.277
Pine Wood, across fiber	.553	Air Space, undivided	.136

PLANS FOR STRUCTURAL INSULATION.

The principles involved in proper insulation of structures may be ascertained from a study of the plans for insulation given in the following pages. The details are given for each specific case.

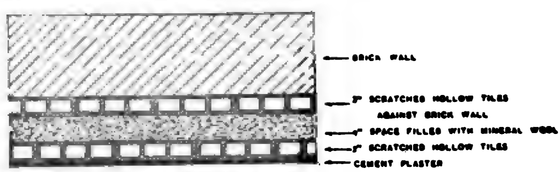
The plans given include designs for brick buildings and wooden buildings, ceilings and floors, wooden insulation for brick buildings, fireproof construction, and also for freezing and brine tanks.

THE FRED. W. WOLF CO.

The plans for "Various Insulations for Cold Storage Buildings" given herewith have the endorsement of the Fred. W. Wolf Company.

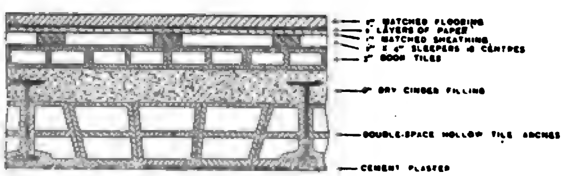
With the respective cuts are given the details of structure and the application of each particular plan shown.

FIG. 149.



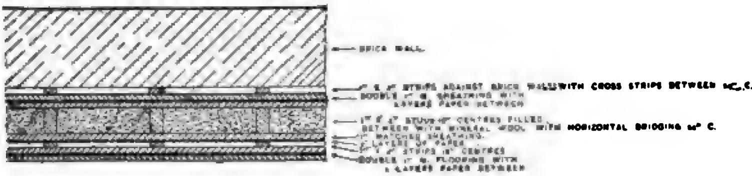
INSULATION OF WALLS FOR FIREPROOF COLD STORAGE BUILDINGS.

FIG. 150.



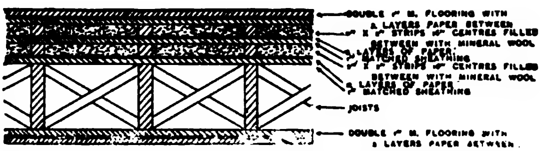
INSULATION OF CEILINGS FOR FIREPROOF COLD STORAGE BUILDINGS.

FIG. 151.



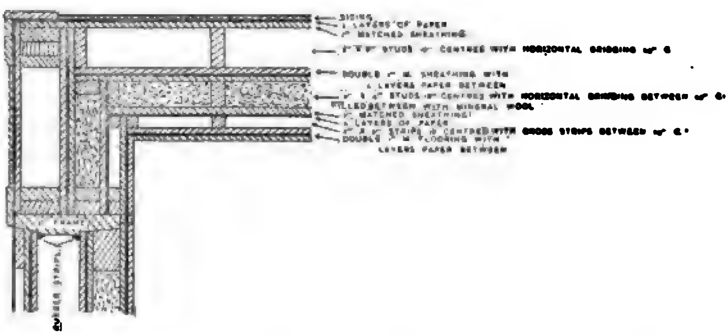
WOODEN INSULATION AGAINST BRICK WALL FOR COLD STORAGE ROOMS.

FIG. 152.



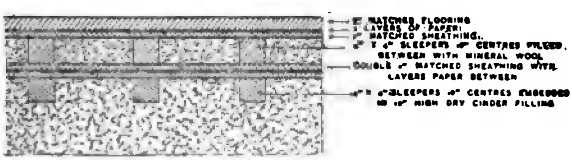
CEILING FOR COLD STORAGE ROOMS WHEN BUILT OF WOOD.

FIG. 153.



WALL FOR COLD STORAGE ROOMS WHEN BUILT OF WOOD.

FIG. 154.



GROUND FLOOR FOR COLD STORAGE ROOMS WHEN BUILT OF WOOD.

The insulating values assigned to these structures are as follows:

Plan shown in Figure.	Heat units transmitted per degree F. difference in temperature per sq. ft. of surface per 24 hours.
149	0.70
150	0.70–0.80
151	1.74
152	2.17
153	2.90
154	1.92

THE DE LA VERGNE SYSTEM.

The plans for insulation advocated by the De La Vergne Machine Company are the results of careful study and an extended experience. The make-up of the various sections is clearly given for the different plans shown.

INSULATION FOR REFRIGERATORS FOR HOTELS AND RESTAURANTS.

Fig. 155. Section through *a*, *b* (from *a* to *b*).

$\frac{7}{8}''$ spruce,
Insulating paper,
$\frac{3}{8}''$ spruce,
1″ air space, 12″ square,
$\frac{3}{8}''$ spruce,
Insulating paper,
$\frac{3}{8}''$ spruce,
1″ air space,
$\frac{7}{8}''$ spruce,
Insulating paper,
$\frac{3}{8}''$ hard wood.

INSULATION FOR BRICK BUILDING.

Fig. 156. Flooring or ceiling.
Section through *a*, *b* (from *a* to *b*).

FIG. 155.

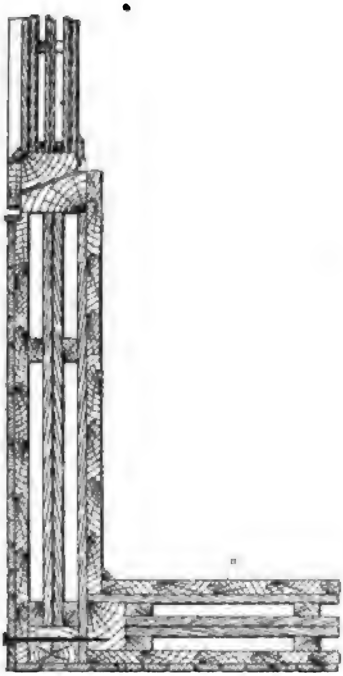
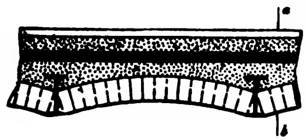


FIG. 156.



1″ asphalt,
2″ concrete,
1½″ pitch,
2″ concrete above beams,
Brick.

Fig. 157. Main wall.
Section through c, d (from c to d).
Brick wall,
2″ pitch,
Brick wall.

FIG. 157.

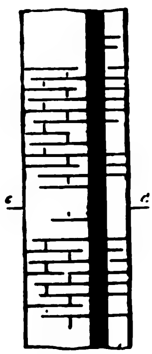


FIG. 158.

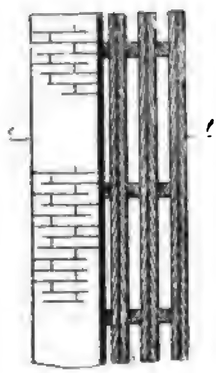


Fig. 158. Main wall for very low temperature.
Section through e, f (from e to f).
Brick wall,
2 coats of pitch,
1″ air space,
$\frac{7}{8}$″ board,
Insulating paper,
$\frac{7}{8}$″ board,
$1\frac{1}{2}$″ air space,
$\frac{7}{8}$″ board,
Insulating paper,
$\frac{7}{8}$″ board,
$1\frac{1}{2}$″ air space,
$\frac{7}{8}$″ board,
Insulating paper,
$\frac{7}{8}$″ board.

INSULATION FOR WOODEN BUILDING.

Fig. 159 A. Ceiling or floor, when room above or below is not cooled.

Section through *a*, *b* (from *a* to *b*).

⅞″ board,
Insulating paper,
⅞″ board,
Floor beams,
⅞″ board,
Insulating paper,
⅞″ board,
* 2″ air space,
⅞″ board,
Insulating paper,
⅞ board.

Fig. 159 B. Partition between two cooled rooms, where difference of temperature does not exceed 20°.

Section through *c*, *d* (from *c* to *d*).

⅞″ board,
Insulating paper,
⅞″ board,
1½″ air space,
⅞″ board,
Insulating paper,
⅞″ board.

Fig. 159 C. Shows method of properly building insulation; the air spaces are divided into small sections by strips, and the joints between the boards in the different layers overlap the joints between the boards in the previous layer.

Fig. 159 D. Main wall or partition between two rooms of which one is cooled and the the other is not cooled.

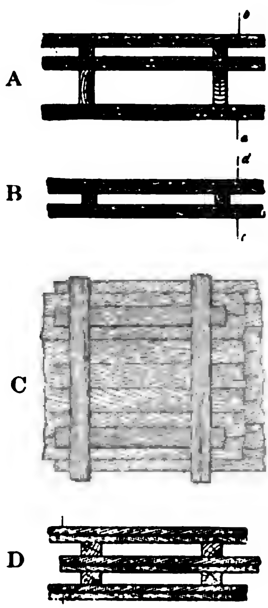
Section through *e*, *f* (from *e* to *f*).

⅞″ board,
Insulating paper,

* If room above is cooled these may be omitted.

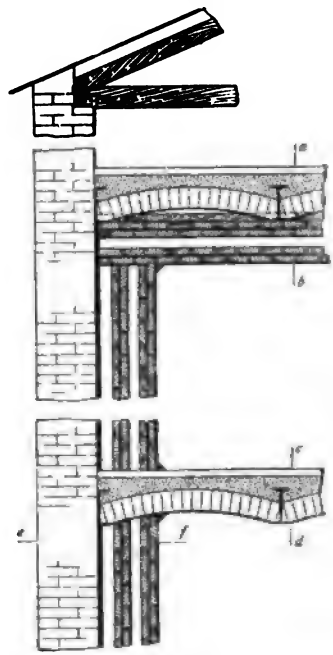
$\frac{7}{8}''$ board,
2″ air space,
$\frac{7}{8}''$ board,
Insulating paper,
$\frac{7}{8}''$ board,
2″ air space,
$\frac{7}{8}''$ board,
Insulating paper.
$\frac{7}{8}''$ board.

Fig. 159.



INSULATION FOR WOODEN BUILDING.

Fig. 160.



INSULATION FOR BRICK BUILDING

INSULATION FOR BRICK BUILDING.

Fig. 160. Ceiling or floor when room above is not cooled.
Section through *a*, *b* (from *a* to *b*).
1″ asphalt,

2″ concrete,
Brick,
Wooden strips,
⅞″ board,
Insulating paper,
⅞″ board,
2″ air space,
⅞″ board,
Insulating paper,
⅞″ board.

Ceiling or floor, when difference of temperature between upper and lower room does not exceed 20°.

Section through *c*, *d* (from *c* to *d*).

1″ asphalt,
2″ concrete,
Brick.

Outer wall.

Section through *e*, *f* (from *e* to *f*).

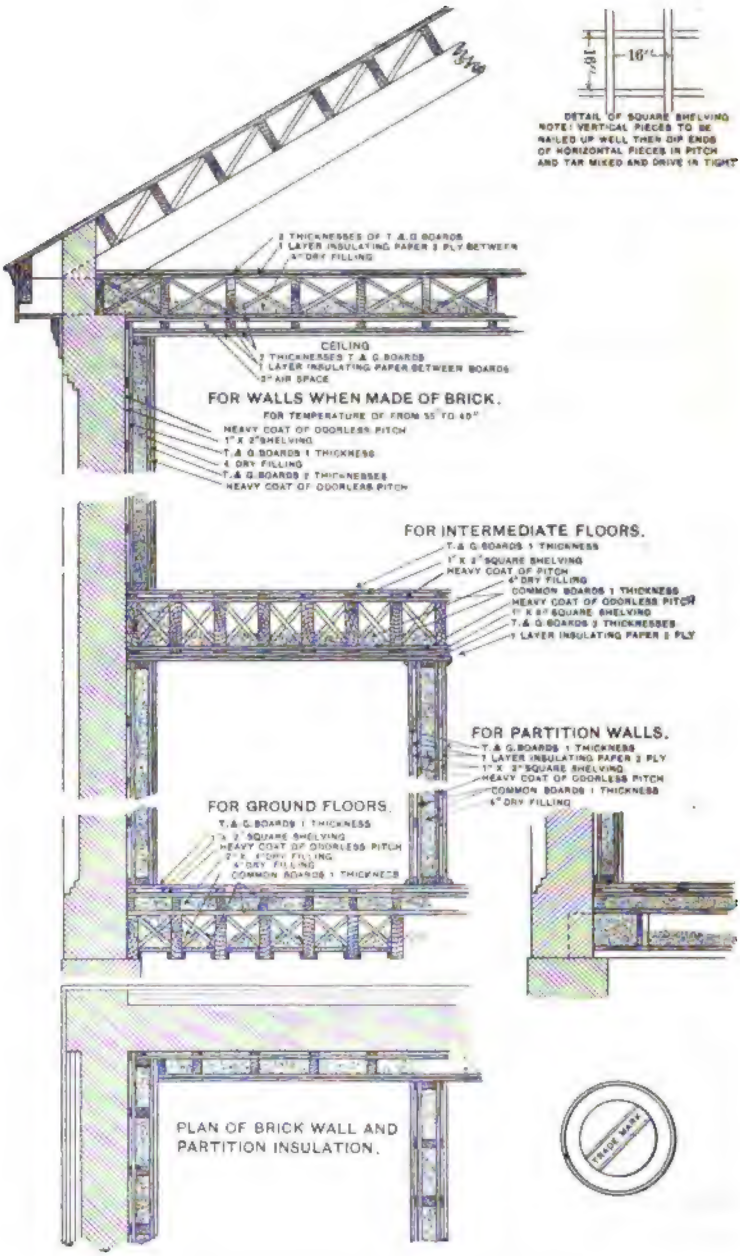
Brick wall,
2 coats of pitch,
2″ air space,
⅞″ board,
Insulating paper,
⅞″ board,
2″ air space,
⅞″ board,
Insulating paper,
⅞″ board.

THE FRICK COMPANY.

The Frick Company, while presenting a variety of plans of "Approved Methods of Insulation," always recommends the best. There is no doubt but that any of the plans presented in the following pages may be set down as good.

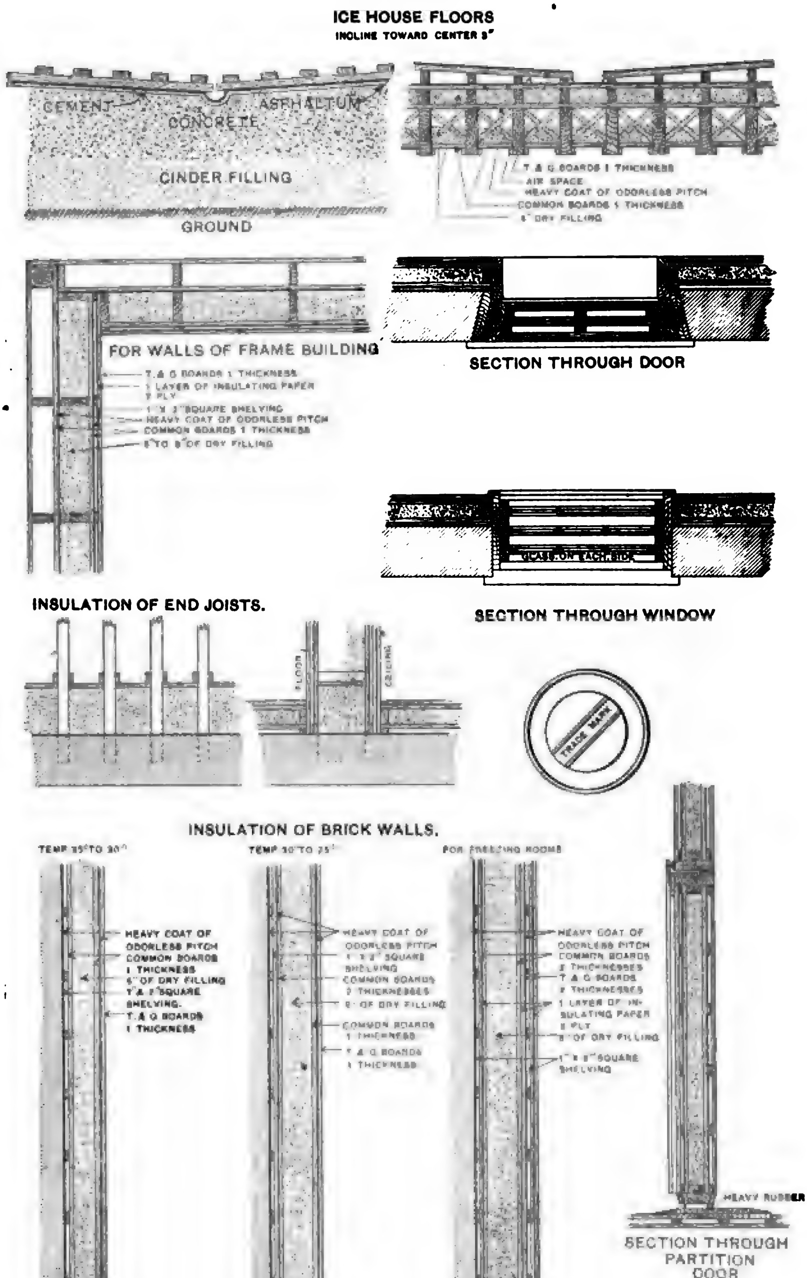
Besides plans for buildings, there is also given a plan for insulation for a freezing tank, Fig. 163.

FIG. 161.



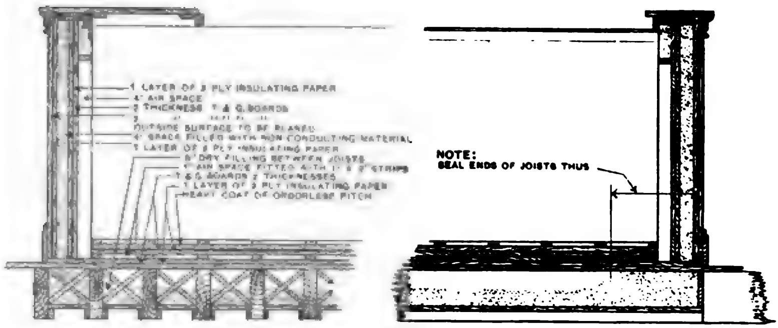
APPROVED METHODS OF INSULATION.

Fig. 162.



APPROVED METHODS OF INSULATION.

FIG. 163.
TANK INSULATION.



LONGITUDINAL SECTION. TRANSVERSE SECTION.

PLANS OF MR. JOHN LEVEY.*

The plans given herewith are presented through the courtesy of the author and of the publishers, the latter being also the publishers of *Ice and Refrigeration.*

MINIMUM TEMPERATURE OF 36° F.

For rooms not carried below 36 deg. F., in frame buildings, the walls need not be filled, but can be built with three good air spaces. The ceilings and floors should have two good air spaces. The floor must be perfectly water-tight, and should have a good open space between the joist and the ground, to prevent decay.

A good cement floor laid on a bed of cinders is ample insulation for this temperature.

In brick buildings for this temperature the brick walls should be well pitched with two coats of well tempered pitch, and then two good air spaces built inside. See diagram, Fig. 164.

MINIMUM TEMPERATURE 32° F.

For rooms to be carried to 32 deg. F., in frame buildings, two air spaces and one space filled with 4″ mineral wool or

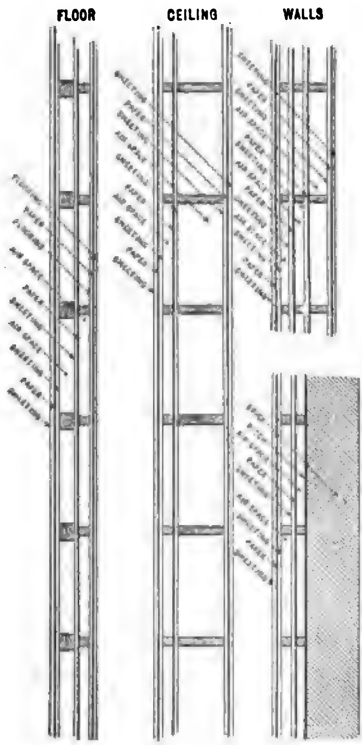
*From "Refrigerating Memoranda."

10″ dry shavings is sufficient. The filled space should be in the center, with an air space on each side.

The ceilings should have two good air spaces and one space filled with 1″ of mineral wool or 4″ of dry shavings.

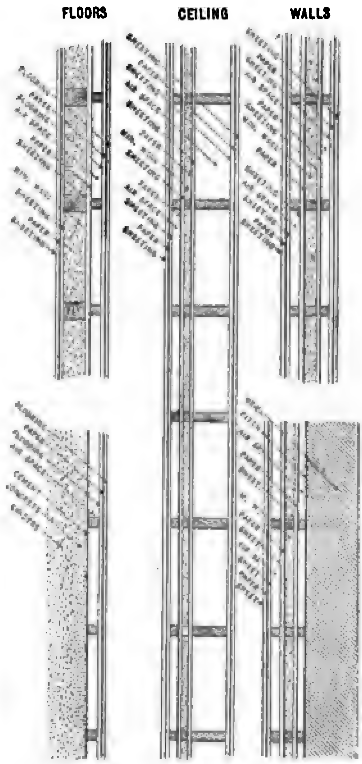
The floor should be water-tight, and have one good air

FIG. 164.



INSULATION FOR 36 DEG. F.

FIG. 165.



INSULATION FOR 32 DEG. F.

space and one space filled with 2″ mineral wool or 6″ dry shavings, and have a good air circulation underneath.

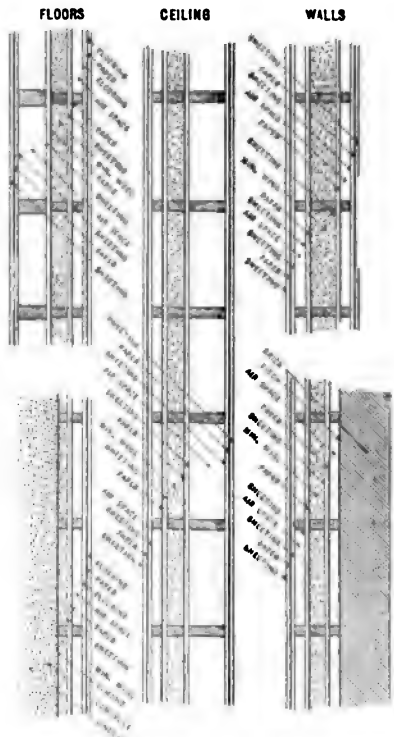
In brick buildings the walls should be well coated with pitch and have two air spaces, and one space filled with 2″ mineral wool or 6″ dry shavings. A good cement floor with one air space and water-tight floor is ample for this temperature. See diagram, Fig. 165.

FREEZING ROOMS.

For freezing rooms, in frame buildings, the walls should have two good air spaces, and one space filled with 6″ mineral wool or 12″ dry shavings—the filled space in the center.

The ceilings—two good air spaces and 4″ mineral wool or 10″ dry shavings.

FIG. 166.



INSULATION FOR FREEZING ROOMS.

The floors—two good air spaces and 4″ mineral wool or 10″ dry shavings, with a good circulation of air underneath.

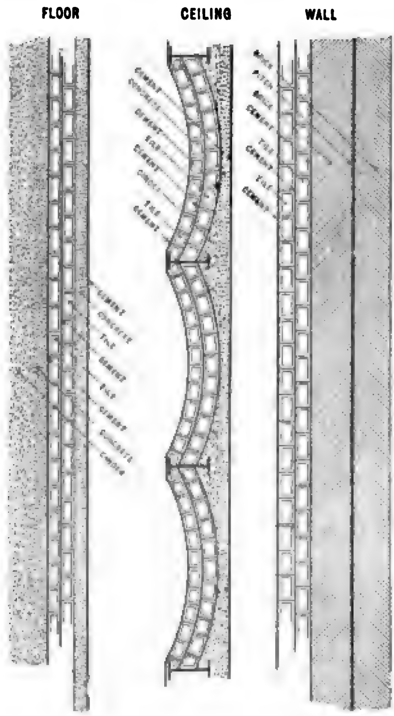
In brick buildings the walls must be well coated with pitch and have two good air spaces and 4″ mineral wool—the filled space in the center.

A good cement floor, with a good air space and 2″ mineral wool. See diagram, Fig. 166.

FIREPROOF CONSTRUCTION.

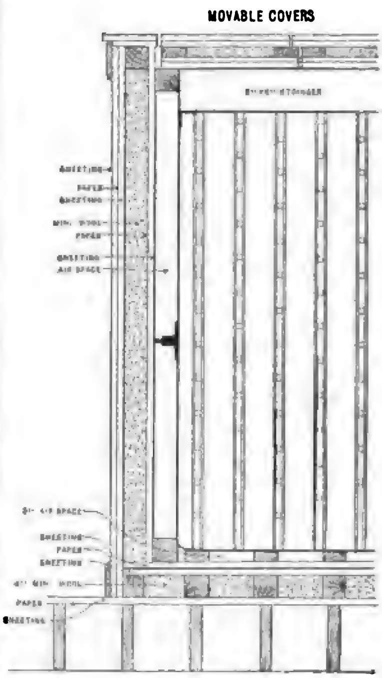
In fireproof buildings, a wall formed of a double brick wall, with a 1″ space between the two parts filled with pitch, lined on the inside with two courses of hollow tile set in cement and plastered over with good cement mortar, makes a good insulation.

FIG. 167.



FIREPROOF INSULATION.

FIG. 168.



INSULATION FOR BRINE TANKS.

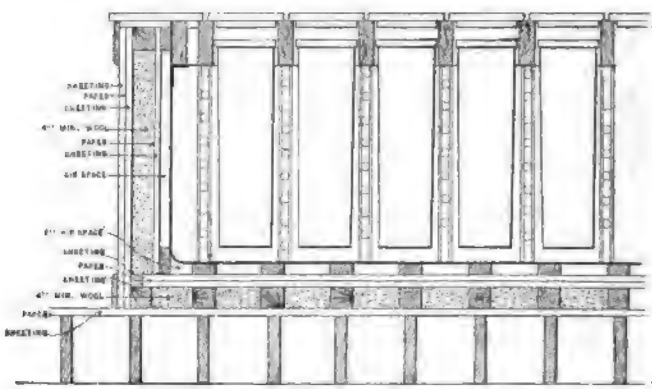
The floor and ceiling of fireproof buildings should be formed by arches made of two courses of hollow tile laid in cement and plastered underneath with good cement mortar. The space above the arches should be covered with well packed dry cinders, covered with a cement floor. See diagram, Fig. 167.

FREEZING TANKS AND BRINE TANKS.

Freezing tanks and brine tanks must always have an air space next the tank to keep the insulation dry. Insulation packed directly against the tank will soon be wetted and frozen through, and the tank will rust out very quickly if of steel, or will soon rot if of wood.

A 4″ air space built of two thicknesses of $\frac{7}{8}$″ D & M. sheeting, with good insulating paper between, then a space filled with 4″ mineral wool or 10″ dry shavings, and two more

FIG. 169.



INSULATION FOR FREEZING TANKS.

thicknesses of $\frac{7}{8}$″ D & M. sheeting with good insulating paper, is the best insulation for brine or freezing tanks.

Freezing-tank covers cannot well be insulated, as they must be comparatively light and movable. Brine-tank covers must be made in sections so as to be handled readily, and should be filled with 2″ mineral wool or 6″ dry shavings, with two thicknesses of sheeting and insulating paper on each side. See diagrams, Figs. 168 and 169.

PLANS BY MR. MADISON COOPER.*

The plans given herewith and the data pertaining to the

* From "Practical Cold Storage."

same are presented through the courtesy of the author and of the publishers, Messrs. Nickerson & Collins.

MODERN HIGH CLASS INSULATION.

The plans for insulation shown in Figs. 170, 171, and 172 represent the result of considerable investigation and practical experience, and may be accepted as reliable and up-to-date.

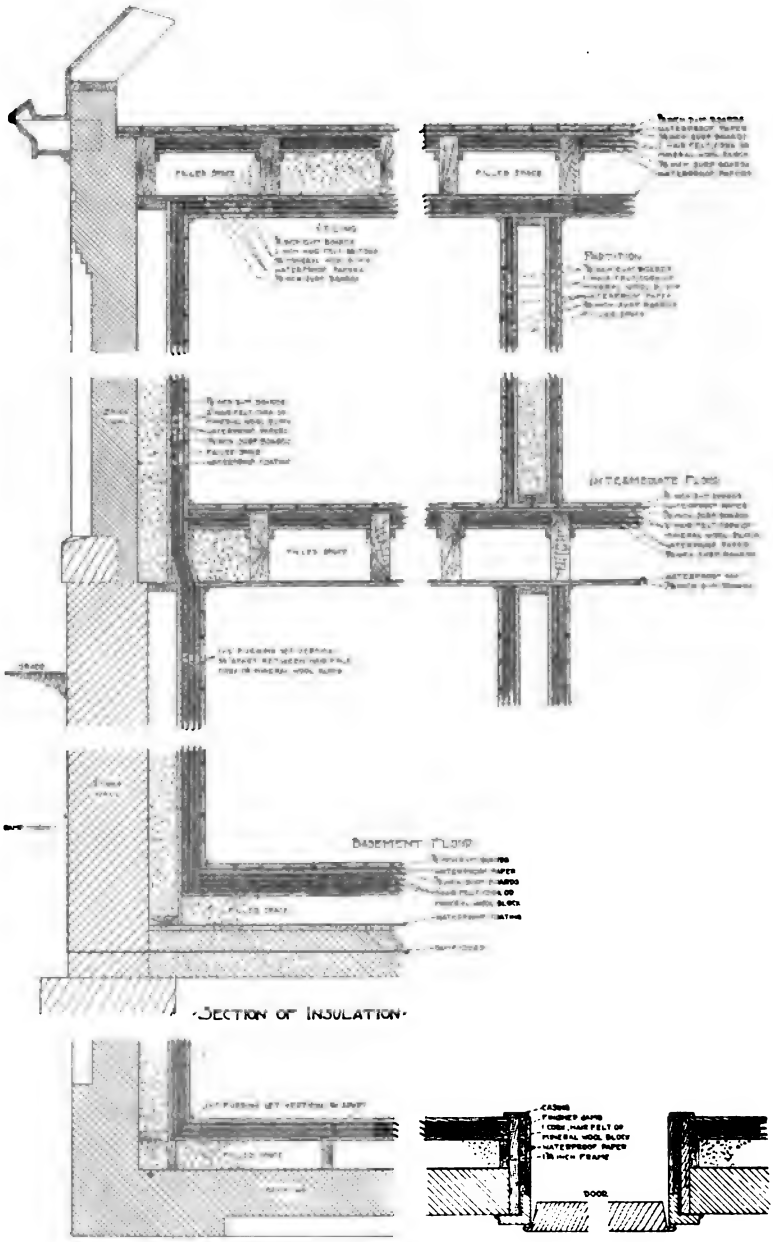
They are adapted for a storage temperature of 30° F., that in Fig. 170 for brick buildings and the plan in Fig. 171 for a wooden structure. The insulating value corresponds approximately to a transmission of .75 B. T. U. per square foot per day per degree difference between inside and outside temperature. The basement in the plan in Fig. 170 is adapted for a temperature of 20° to 25° F. For sharp freezing purposes the filled space should in this case be increased from eight inches, as shown, to ten inches and an additional thickness of sheet material should be used.

The construction in Fig. 170 is made up of a 12-inch brick wall, 8 inches of shavings and 5 inches of sheathing, sheet material and paper.

The details are clearly shown in the illustrations. It may be well to call attention to the reasons for the adoption of the arrangement as shown. The feature aimed at in addition to initial efficiency is durability.

"This is accomplished by placing the indestructible materials, such as waterproof paper, and mineral wool block, sheet cork or hair felt in successive layers on the side next to the storage room where the conditions are most severe. These severe conditions are caused by a tendency of the enmeshed air in all insulating materials to condense the moisture held in suspension when subjected to low temperatures. This moisture will impair the durability of some materials, such as sawdust, shavings, etc. . . . The moisture condensed would be greatest in the layer nearest the cold side of the partition and would gradually diminish in each layer toward the high temperature side, where it would be perfectly dry. . . . Air space construction showed the greatest condensation, wide

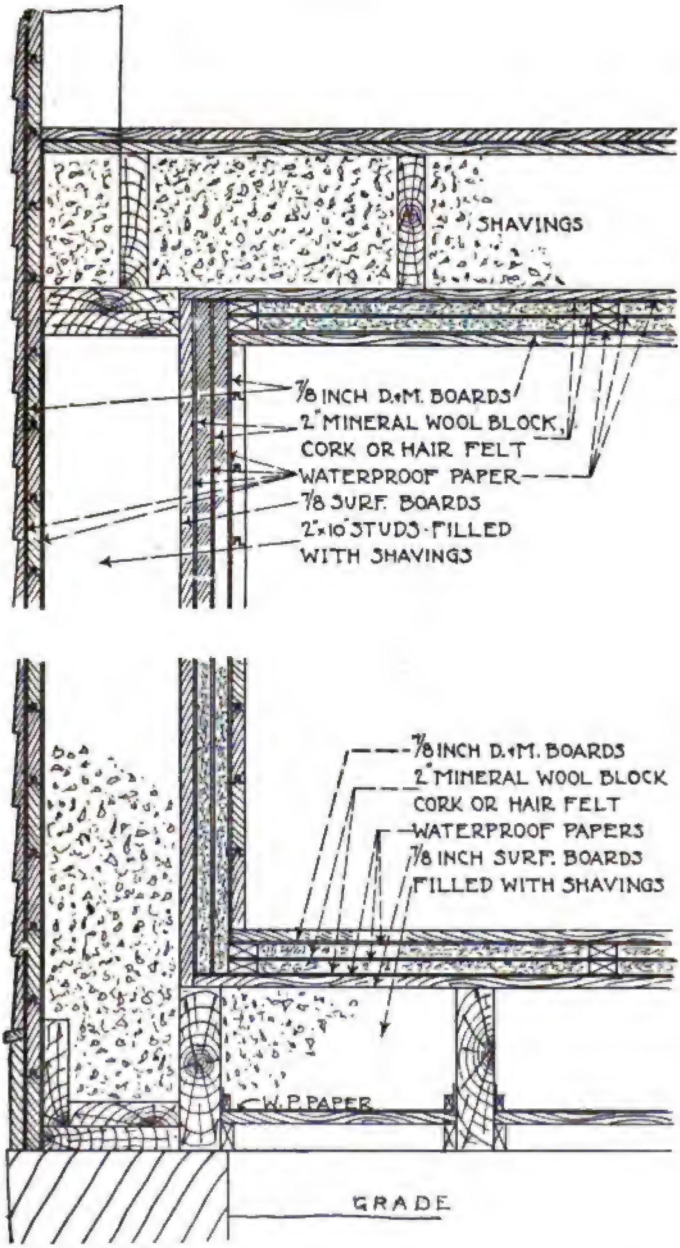
FIG. 170.



·PLAN OF INSULATION·

INSULATION FOR BRICK BUILDING.

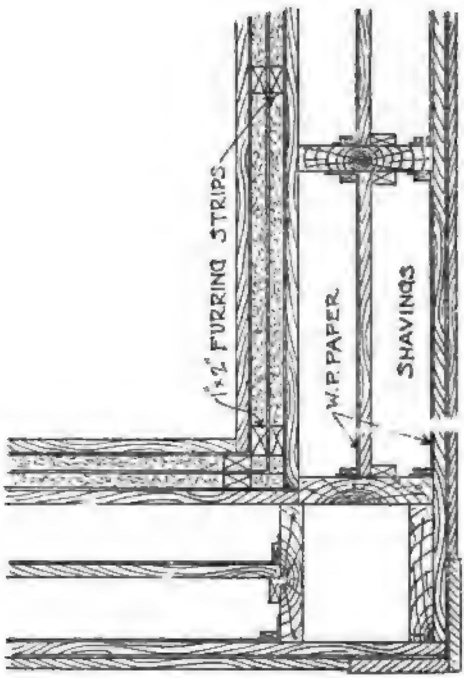
Fig. 171.



SECTION SHOWING INSULATION FOR FRAME BUILDING.

filled spaces came next and the high grade of sheet materials divided by waterproof paper showed the best. From the above it is evident that high-grade materials should be used next to the storage rooms, as they will not deteriorate as rapidly with the presence of moisture. This construction also protects the loose filler in the filled space, which is removed

FIG. 172.



PLAN OF INSULATION FOR FRAME BUILDING.

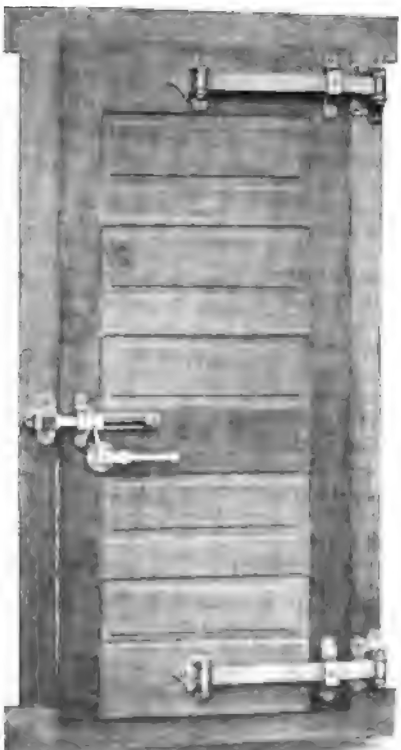
further from the inside wall, therefore making its duty less severe as regards the action of moisture."

Another feature to be noted in regard to Fig. 170 is the continuous construction of the wall insulation from the floor of lower story to ceiling of upper story. This avoids repetition of joints at each floor as is the case where the floor insulation is carried out to the wall at each floor, and accordingly reduces the liability of air leakage at the joints.

REFRIGERATOR DOORS.

The importance of giving due attention to the construction of doors and windows in a modern cold-storage structure is well recognized. Windows are as a general thing studiously avoided. Where necessary they are of course doubled or trebled.

FIG. 173.



THE JONES AUTOMATIC DOOR.

The construction of doors has been well developed, a number of first-class articles being on the market; the one shown is made by the Jones Cold Storage Door Co., Hagerstown, Md.

In general a complete outfit consists of a sill, frame and

door proper. In some cases with a cement floor the sill may be dispensed with. An important feature is that of seals, to close up open space between the door and sill and along edges at sides and top. The door proper is a composite structure provided with insulation. Doors may be made practically fireproof by enclosing with sheet metal or may be made strictly fireproof by special construction. Other special features are hinges and fasteners.

JONES REFRIGERATOR DOOR.

It is our object to call attention to a few of the special features of the doors under consideration, without making ex-

Fig. 174.

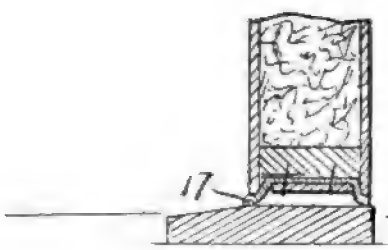
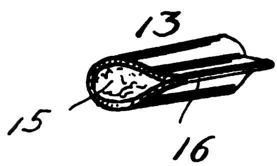


Fig. 175.



tended reference to the entire line produced to meet various requirements. The ordinary standard door is shown in Fig. 173. The general plan will be clear from an inspection of the sectional views in Figs. 174, 175 and 176, and the subjoined explanation of the different parts. Important parts are the hinges and fastener, to which special references are given.

DETAILS OF REFRIGERATOR DOOR.

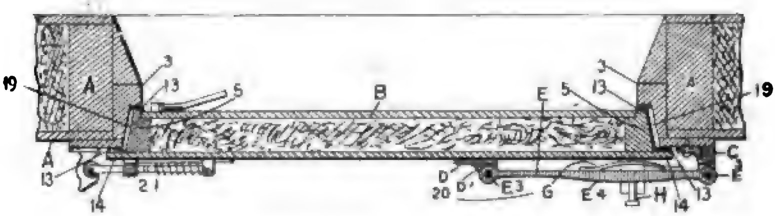
Fig. 174, sectional view of bottom of door and sill. Fig. 175, sectional view of packing or gasket. 13, waterproof cover skin of packing; felt packing is used because when pressure is taken off it immediately expands and resumes its former shape; 16, the part by which it is tacked to the rabbet

strip of the frame and the overlapping part of the panel. Fig. 176, sectional view of door and frame. 3, shows the jamb with beveled strip butted up tight against jamb after frame is secured in the wall; 5, the stiffeners at the side; 13, shows where packings are placed; 14, shows front panel of door overlapping the frame; 19, the dead air-space between the door and frame made by the two rows of packing or gasket; 20, the hinge; and 21, the fastener.

Beveled sill sinks in floor $1\frac{3}{4}''$, as shown in Fig. 174.

In Fig. 176 is shown the wall A; B, indicates the insulation in door, which is always encased in waterproof paper; C, is the hinge casting, secured to frame by bolts; D, casting at-

FIG. 176.



tached to door; E, the long hinge bar; G, the spring which forces door in against the packing, the pressure of which is adjusted by the set screw H.

HINGES.

A hinge consists of a casting placed near outer edge of casing on frame, and one adjacent center of door, pivotally connected to opposite ends of a long, well-shaped bar which passes through a guide or stay that is fastened on near the heel of the door. A curved steel spring is secured in this guide, pressing against the back of bar, forcing the door in tight, compressing the packings. This pressure is regulated by a set-screw.

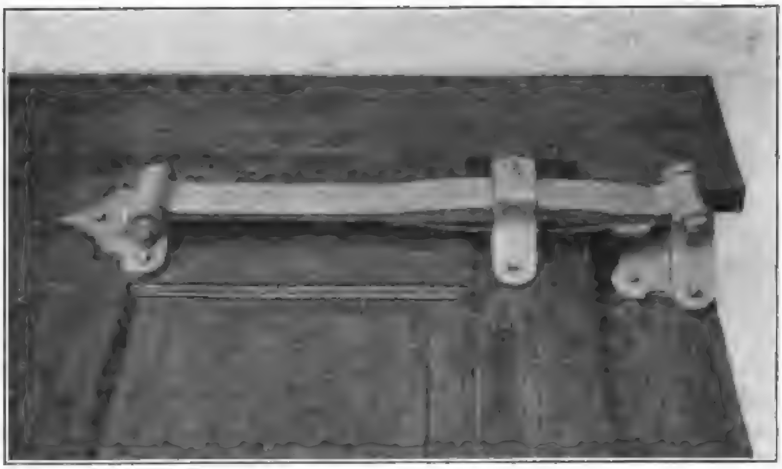
The hinges are extra heavy and strong, being of galvanized iron or polished brass. The steel spring forces the door in

tight, but set-screw regulates it, so as to ensure the same pressure all around door. See Fig. 177.

THE FASTENER.

The fastener is simple and unique. It consists of a bedplate which is fastened to the door, in which slides a spring-projected bolt whose outer end is supplied with a roller to engage keeper on frame. In closing the door the roller strikes

FIG. 177.



THE JONES ADJUSTABLE SPRING HINGE.

slanting surface of keeper, forcing bolt back on spring until after passing most prominent part of keeper, when this spring gets in its work by forcing bolt out again, the roller going in behind keeper on a slanting surface, which produces a wedge action, forcing door in tight and compressing all packings.

To work the fastener a lever handle is attached to a shaft running through the door. The lever engages the bolt, and pressing down on the lever draws the bolt out, releasing the door.

A second lever handle is attached to shaft on inside of door, so that it is opened as easily from one side as the other.

There is a round plate on each side of door, through which the shaft passes, the under side of which is hollowed out, and in that hollow is placed a rubber packing, or washer, to exclude moisture and air. In using the door simply press down the lever, the door comes open, walk through, give door a push, and it closes and fastens automatically.

The illustration, Fig. 178, represents the roller bar about to engage keeper as the door is being closed.

FIG. 178.

THE JONES AUTOMATIC FASTENER.

INSULATION.

We give here some of the various methods of insulation at present in vogue. 1st, granulated cork encased in waterproof paper; 2nd, three layers of waterproof paper, two layers of $\frac{3}{4}''$ hair felt with a dead air space between; 3rd, two layers Linofelt, four layers waterproof paper with a dead air space between; 4th, two layers of Linofelt, four layers waterproof paper, one layer 2″ Lith; 5th, three layers 1″ hair felt, four layers waterproof paper; 6th, three layers 1″ sheet cork, four

layers waterproof paper; 7th, one layer 1″ sheet cork, two layers 1″ hair felt and four layers waterproof paper.

The reason for the use of several thicknesses of the same material is because that allows the use of paper between each layer, for the dampness must be excluded if possible, and plenty of good waterproof paper is very desirable, as it also cuts off the passage of air through the door at the same time.

Whenever warm and cold air come in contact they produce a condensation of moisture and water is precipitated, which, running down over the door, freezes and coats that side with ice.

Having several kinds of material of different degrees of density, retards the circulation of air more effectively and makes a better insulation than if the whole space is taken up with one kind of material, even though the kind used be of the best.

Doors insulated as above are adapted for temperatures of about 34° F. Freezer doors for temperature of about 25° F. may be built on similar lines by providing slightly additional insulation and consequent increase in thickness. It is good practice where extremely low temperatures are required to provide air locks.

LITH AND LINOFELT.

Insulations in board and quilt form produced by the Union Fibre Co. are known as Lith and Linofelt, respectively. These materials, combined with a liberal and judicious use of waterproof cement, called antiaqua, and Portland cement plaster, permit of making a strictly water-proof, vermin-proof, and efficient insulation.

Degummed flax fibre, made from straw, unbleached, enters into the composition of both the products. Linofelt is made of this material, about one-half inch in thickness, sewed between two thicknesses of three-ply water-proof paper. Antiaqua cement is used for water-proofing the edges at floors and ceilings and around all openings. Linofelt is soft and flexible, and is shipped in rolls.

Lith is a board insulation made up of silica rock wool combined with the degummed flax fibre. It is essentially a mineral wool product made up in board form, convenient for structural purposes. The mineral wool ingredient is largely a silicate of lime, light, fibrous, elastic, and permanent in chemical composition. It is produced in board form of dimensions 18″x48″, and of one-half, one, two, three, or four inches in thickness.

RESULTS OF TESTS.

Herewith are given results of tests of the insulation values of different combinations of materials, including some with the materials under consideration:

	Structure of Insulation.	Heat units transmitted per 24 hours per degree F. difference in temperature.
I.	Four boards, two papers, solid, no air space	4.28
II.	Four boards, two papers, with one air space	3.71
III.	Three double boards and paper and two air spaces	3.15
IV.	Four " " " " " three air spaces.	2.70
V.	Four boards and paper and 1″ of Linofelt	2.30
VI.	Two boards and paper, one air space, 2″ Lith, and one paper and board	1.79
VII.	One board, paper, 3″ Lith, paper, one board	1.59

References to boards and paper apply to $\frac{7}{8}''$ spruce boards and P. and B. insulating paper.

INVESTIGATIONS OF STRUCTURAL INSULATION.

The Nonpareil Cork Manufacturing Co. conducted a series of experiments on insulation on an extensive scale and with specially designed apparatus adapted to produce valuable and reliable results.

Their apparatus consists of an insulated room 12 x 10 x 8 feet, the temperature of which can be held at any point desired, from zero Fahrenheit up, by means of a compression machine operating with direct expansion. A uniform temperature throughout the room is secured by forced circulation, an electric fan being used to drive the air up over the expan-

sion coils which are inclosed at one end of the room. The air passes out and down through a false ceiling having graduated perforations arranged to allow a uniform amount of cold air to fall in all parts of the room. In the center of the room is an insulated box, 3 x 3 x 6 feet inside measurement, having one side removable. It contains an electric heating coil and a small electric fan arranged to give a circulation of air and insure a uniform temperature in all parts of the box. Standard thermometers, both mercurial and recording air pressure, reading $\frac{1}{10}$° F., are so placed as to give the temperatures of the refrigerated room and the heated box, the readings being taken outside the room. This obviates any necessity of the operator entering the refrigerated chamber while the test is being made. The Weston standard ammeter and voltmeter measure the electricity supplied to the fans and heating coil, and a suitable rheostat regulates the amount of the current.

The method of determining the heat conductivity of any insulating construction is as follows:

The temperatures of the room and box are respectively lowered and raised until they conform to the conditions under which the proposed insulation will be used. Then the amount of electricity or heat supplied to the box is gradually diminished by means of the rheostat, until the point is reached where the temperature in the box remains constant. It is evident that at this point the radiation must exactly equal the amount of heat supplied, or there would be a rise or fall in temperature, as the case might be. After the supply and radiation have been maintained constant for two hours, readings are taken every five minutes for three hours more. If they do not vary more than one-tenth of 1° F. they are considered practically exact. The average is taken as the permanent radiation of the box under the given conditions. The box contains 100 square feet of surface, measured at the center of the insulation, consequently $\frac{1}{100}$ of the total radiation is the rate per square foot. This rate being obtained, the removable side of the box is replaced with a side constructed of the insulation whose value is desired. The test is then repeated,

and the total heat loss from the changed box will be greater or less, as the case may be. The removable side contains twenty square feet surface, therefore eighty square feet of the box remain unchanged, and the radiation through them must be the same as before. This amount is at once determined from the previous tests, and the difference between the total heat loss from the box in its changed condition and this amount must give the radiation through the twenty square feet comprising the new side which has been put in. One-twentieth of this amount is of necessity the rate per square foot, and this, divided by the difference in temperature between room and box, will give the exact radiation per square foot of surface per degree of difference in temperature.

As a result of the investigations it has been found that the loss of heat per degree difference in temperature is constant for a given construction. Accordingly, it is possible to give a definite value for the efficiency in heat units transmitted per degree difference in temperature per square foot of surface.

This value is accordingly given herewith for various combinations together with details as to construction in each case.

It may be further noted that in the case of air spaces, the thickness of the same is immaterial, a thickness of 2″ of air being equally as efficient as one of 3″.

NONPAREIL CORK CONSTRUCTION.

Thickness of Cork.	Heat units transmitted per degree diff. in temp. per sq. ft. surface per 24 hours.	Figure.
	SOLID CONSTRUCTION.	
1″	3.25	179
2″	2.60	180
3″	2.25	181
	WITH AIR SPACE.	
3″	1.70	182
4″	1.20	183
5″	.90	183

FIG. 179.

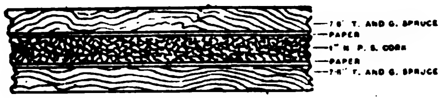


FIG. 180.

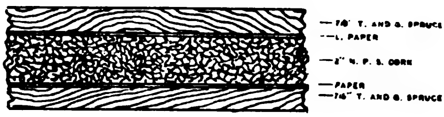


FIG. 181.

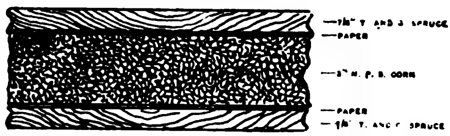


FIG. 182.

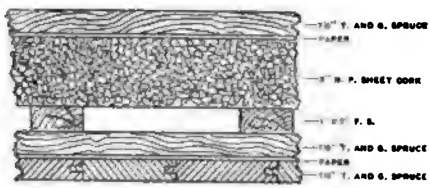
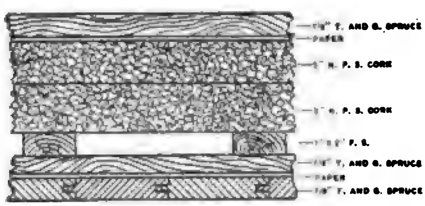


FIG. 183.



BOARDS AND AIR SPACE.

Number of air spaces.	Heat units transmitted, etc.	Fig.
0	4.75	184
1	4.25	185
2	3.45	186
3	2.70	187

FIG. 184.

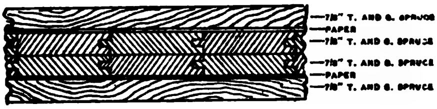


FIG. 185.

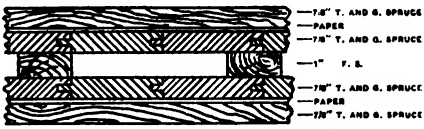


FIG. 186.

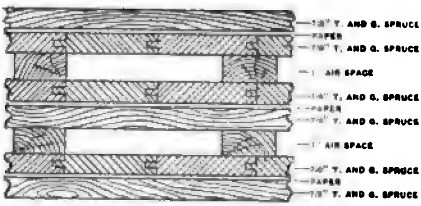
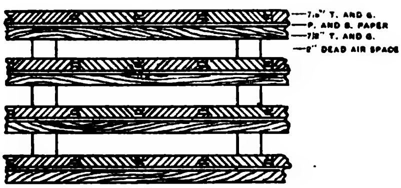


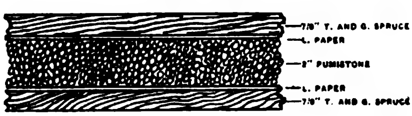
FIG. 187.



STERILIZED PUMICE CONSTRUCTION.

Thickness of Pumice.	Condition.	Heat units transmitted, etc.	Fig.
2″	Dry.	3.40	188
2″	Slightly damp.	3.90	188

FIG. 188.

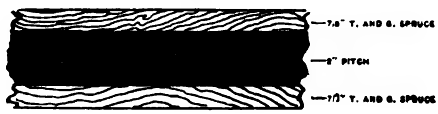


PITCH CONSTRUCTION.

Thickness of pitch.	Heat units transmitted, etc.	Fig.
1″	4.90	189
2″	4.25	190

FIG. 189.

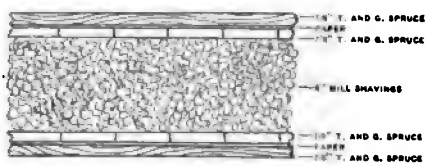
FIG 190.



MILL SHAVING AND MINERAL WOOL CONSTRUCTION.

Material.	Condition.	Thickness.	Heat units transmitted, etc.	Fig.
Mill shavings.	Dry.	8″	1.35	191
Mill shavings.	Slightly moist.	8″	1.80	191
Mill shavings.	Damp.	8″	2.10	191

FIG. 191.



PART IV.

USEFUL INFORMATION AND TABLES.

CHAPTER I.

PRACTICAL REMARKS ON ICE-MAKING.

THE operating expenses of an ice plant of a given capacity can be pre-determined, as all expenses connected with the factory are fixed quantities for given rates of production. It is in every sense a routine business, as susceptible of exact calculation as the business of pumping a given quantity of water.

The greater the capacity of the plant, the less the cost per ton of production. Plants of a daily capacity as low as one ton prove remunerative investments.

Aside from the influence of the capacity of a plant, the cost of making ice also varies slightly with different localities, being affected by cost of fuel and labor, the difference being so little, however, that we find ice manufactured and sold in the South quite as cheaply as natural ice in the Northern cities. It is a matter of congratulation that the machine-made ice has supplanted natural ice wherever introduced.

PURITY OF MACHINE–MADE ICE.

From a sanitary or hygienic point of view, the wholesomeness, cleanliness and clearness of ice made by machinery has attracted the attention of physicians, who recommend its use instead of natural ice.

The water used for freezing in ice moulds is chemically pure (distilled water), and of course free from all organic matters, disease germs, etc., seen in natural ice, which cause diph-

theria, fevers and kindred diseases. It is rare that natural ice can be found entirely free from impurities, as it must be gathered from filthy streams, stagnant ponds, canals, shallow and still waters, or basins into which sewers have emptied, or which have been contaminated by receiving the surface washings of the soil, at all times laden with deleterious organic and decomposed animal matters.

The best natural ice is taken from the potable waters of the great Northern rivers and lakes, or large and deep bodies of water, which afford, by reason of the great severity of the winters, an immense harvest, and, under favorable conditions, clear crystal ice. This ice, under the microscope, is teeming with organic life, and is far from being as pure and wholesome as ice manufactured from distilled waters.

While Nature manufactures ice without cost to any one, the cost of cutting, handling, transportation, loss by waste and meltage, and expense of storing when gathered from the ice-producing localities of the North is so great that, even in cities as far north as New York, Philadelphia and Chicago, manufactured ice can be produced and sold at a handsome profit and in direct competition with the famous "Northern lake" and "Kennebec ice," as practically demonstrated by many ice dealers who are profitably operating ice factories.

An analysis of the reasons why ice can be manufactured and placed on the market cheaper than that gathered from natural sources will be interesting, aside from a consideration of the unquestioned superiority of the machine-made article.

Manufactured ice has one advantage among others, of being made in the very market in which it is sold and consumed, hence suffers no loss and occasions no extra expense for transportation and storage. The actual demand is supplied from day to day by making the ice as called for, drawn from the freezing moulds without waste, and supplied to the consumer direct, without intermediate storage and loss of from 20 to 50 per cent. by melting in transportation.

WHAT IS NEEDED TO ESTABLISH AN ICE FACTORY?

The first and most important thing is a market for the ice. While the home or local demand may not be sufficient to justify entering the business, your proposed ice factory may be so located that it may serve as a center of supply for outlying towns easily reached by railroad or wagon deliveries, and thus the aggregate demand of the vicinity may justify the erection of a plant of not less than two tons capacity. (The size, however, will depend upon price of ice obtainable.) It is well known, and an encouraging thing to know, that the demand for ice grows larger year by year, and the introduction of first class manufactured ice in a locality is simply the beginning of a constantly increasing and substantial business. A certainty of supply creates a demand.

WATER SUPPLY.

Water for use in the factory is the next most important consideration. Be sure that you can obtain a reliable supply of water at all times and all seasons, calculating upon a basis of at least three to four gallons per minute for every ton of proposed ice-making capacity. Water should be suitable for feeding boilers, and is needed for condensing the ammonia, filling ice moulds, distilling and cleaning. Preferably, the water should be as cold and pure as possible, and if taken from the earth from an artesian or deep well, all the better, because colder.

ICE-FACTORY BUILDINGS.

These may be made of wood or brick, depending upon the building regulations or fire restrictions of the city or locality, as well as upon the ambition and means of the owner. In most cases a plain and well-built wooden building is used. The building should be divided into the following compartments: boiler room, engine or ice-machine room, tank room, ice-storage house having an ante-room, and a business office.

The condensing and distilling apparatus may be placed upon the roof, or in a special room. In either case they should

be protected by a roof, with open sides of lattice or screen work, through which air can circulate. A convenient platform for loading into wagons and weighing the ice is also required.

COLD STORAGE.

Special cold storage rooms for preserving butter, eggs and perishable products may be added to the premises with profit if the locality offers any inducement to provide for this kind of business.

BOILER POWER.

Secure ample boiler power, and a point worth knowing to your future advantage, especially in larger plants, is to use two boilers, either of which will run the machinery while the other is being repaired or cleaned. This is well to take into consideration, as ice factories are run continuously, and with a single boiler it means a stoppage of the whole factory in case of accident or necessary cleaning of boilers.

ICE CANS OR MOULDS.

The sizes of cans in common use are shown in the following table:

50	Pound	Block	of Ice,	6″ x 12″ x 28″
100	"	"	"	8″ x 15″ x 35″
200	"	"	"	11″ x 22″ x 35″
300	"	"	"	11″ x 22″ x 45″
400	"	"	"	11″ x 22″ x 60″

All cans should have wrought-iron bands, be well braced, riveted and soldered smooth inside, galvanized throughout, and standard taper.

TRAVELING CRANE AND ICE-CAN HOIST.

A free-moving light traveling crane for each tank, with geared hand hoist, makes it easy work for one man while on watch to take care of 10 to 15 cans per hour. An air hoist capable of handling two cans at a time, or an electric crane capable of handling any desired number of cans may be used.

RUNNING AN ICE FACTORY.

It is important in ice-making, where the greatest production with the least possible cost is desired, to run the plant day and night, making the operation continuous. Not only this, but the best conditions to insure the best quality and greatest quantity should be observed and uniformly held. For instance, in drawing the ice, it must be done with regularity, so many cans each hour, day and night, and the drawing uniformly distributed over the whole area of the tank.

It is hardly necessary to suggest the reason why the ice should be drawn systematically, the machine run at regular speed, steam-pressure, water-supply, boiler-feed, and all temperatures maintained, as near as possible, uniform.

CLEANLINESS.

Keep all parts of the apparatus clean and in good order. Let nothing become foul or dirty about the distilling apparatus, ice cans or tanks. Means should be provided for purging the entire distilling system by steam, and the use of a scrubbing brush and harmless solvents is recommended. Change charge in your filters as often as required.

THE ICE FACTORY CREW.

The ice factory crew is divided in two watches of twelve hours each. For instance, on a 50-ton ice plant there would be one engineer, one fireman and two tankmen on each watch.

OPERATING EXPENSES.

Operating expenses of a factory are made up of cost of fuel light, oil and waste, slight loss of chemicals, sundry small repairs, salary of superintendent and engineer, with wages of firemen, tankmen and other labor. It is a paying investment to employ good men and best fuel obtainable.

A table of approximate cost of ice-making is given in Chapter V, Part I, on Ice-Making, page 55, and a similar table with somewhat different basis on the following page.

APPROXIMATE COST OF OPERATING ICE FACTORIES.

Tons ice per day.	Engineers $1.50 to $5.00 per day.		Oilers $1.25 per day.		Firemen $1.25 per day.		Tankmen and Laborers $1.00 per day.		General Helpers $1.25 per day.		Coal 15 cts. per Cwt., or $3.00 per ton.		Oil, Waste, Lights and Sundries.	Daily Operating Expenses.	Ice per ton.
1	2	$3 00		...		..		....		...	500	$0 75	$0 50	$4 25	$4 25
2	2	3 00		...		...		....		...	1,000	1 50	50	5 00	2 50
4	2	3 00		...		...	1	$1 00		...	2,000	3 00	50	7 50	1 88
6	2	3 50		...		..	1	1 00		...	2,700	4 05	50	9 05	1 51
10	2	3 50		...		....	1	1 00		..	4,500	6 75	75	12 00	1 20
15	2	3 75		...		...	2	2 00		...	6,700	10 05	1 00	16 80	1 12
20	2	3 75		...		..	2	2 00		...	8,000	12 00	1 00	18 75	94
25	2	4 00		...	2	$2 50	2	2 00		...	8,400	12 60	1 10	22 20	89
30	2	4 00		...	2	2 50	2	2 00		...	9,500	14 25	1 25	24 00	80
35	2	4 00		...	2	2 50	2	2 00		...	10,800	16 20	1 50	26 20	75
40	2	4 50		.	2	2 50	3	3 00		..	11,500	17 25	1 75	29 00	73
50	1	2 75		..	2	2 50	4	4 00		..	14,300	21 45	2 00	34 45	69
60	2	5 00	1	$1 25	3	3 75	4	4 00		..	16,000	24 00	2 25	40 25	67
75	2	5 00	1	1 25	3	3 75	4	4 00	1	$1 25	20,000	30 00	3 00	48 25	65
100	2	5 50	2	2 50	4	5 00	6	6 00	1	1 25	25,000	37 50	4 00	61 75	62

CHAPTER II.

TABLES OF TEMPERATURES AND RATES OF STORAGE.

TEMPERATURE FOR PRESERVING PRODUCTS.*

The following table, compiled partly from tables published in American Gardening, partly from "Hiles's Ice Crop," and partly from results obtained by experiments, shows the best temperature for preserving some of the most common horticultural products, and indicates the packages in which they should be stored and the time they may be expected to keep:

Product.	Temperature, degrees.	Package.	Time.
Apples, summer . . .	38 to 42	Barrels or boxes . .	2 to 4 months.
Apples, winter	32 to 35	Barrels or boxes . .	5 to 8 months.
Pears	33 to 38	Barrels or boxes . .	2 to 4 months.
Peaches	36 to 38	Crates	2 to 4 weeks.
Grapes	38 to 40	In sawdust in boxes .	6 to 8 weeks.
Plums	38 to 40	Crates	2 to 4 weeks.
Berries and cherries . .	40	Quart boxes	1 to 3 weeks.
Bananas	40	Crates	8 to 12 weeks.
Lemons, oranges . . .	40	Crates	8 to 12 weeks.
Figs, raisins	40	Boxes	8 to 12 weeks.
Watermelons	40	. . . .	3 to 6 weeks.
Muskmelons	40	. . . .	2 to 3 weeks.
Tomatoes	38 to 42	Crates	2 to 4 weeks.
Cucumbers	38 to 40	Crates	1 to 3 weeks.
Celery	35	Boxes.	
Cranberries	34 to 38	Barrels.	
Onions	34 to 40	Barrels.	
Potatoes	36 to 40	Barrels.	
Asparagus, cabbage . .	34	Boxes.	

* Experiment Station of the Kansas State Agricultural College, Horticultural Department. Bulletin No. 84. April, 1899.

TEMPERATURE FOR COLD STORAGE.*

Merchandise.	*Temperature degrees F.*	*Merchandise.*	*Temperature degrees F.*
Apples	32-36	Game, frozen	25-28
Ale	33-35	Ginger ale	36
Asparagus	34-35	Grapes	34-36
Bananas	34	Hams, fresh	20
Beef, fresh	33-35	Hogs	29-32
Beef, dried	36-40	Honey	45
Beef, corned	38-40	Hops	32-40
Beer	33-35	Lambs	32
Beer, bottled	45	Lard	38-40
Berries	36-40	Lard oil	40
Buckwheat flour	36-40	Lemons	33-36
Butter	18-25	Liver	20-30
Butterine	18-25	Maple sugar	40-45
Cabbage	34-35	Maple syrup	40-45
Canned goods	35-40	Meats	35-40
Canteloupes	34-35	Nuts	35-40
Calves	32-33	Oils	35
Carrots	34-35	Onions	36
Celery	34-35	Oranges	34-36
Cheese	28-34	Ox-tails	30
Chestnuts	33	Oysters in shell	30-35
Cider	30-35	Oysters in tubs	25
Cigars	32-35	Parsnips	34-35
Corn meal	36-40	Peaches	34-36
Cranberries	33-36	Pears	34-36
Cured goods	20-35	Pork	40
Dates	50-55	Porter	33
Dried beans	32-40	Poultry, frozen	20-28
Dried beef	36-40	Sardines	35-40
Dried corn	35	Sauer kraut	35
Dried fish	35-36	Sheep	32
Dried fruits	35-40	Shoulders, fresh	20
Dried peas	35-40	Sweet corn	35
Eggs	31-33	Syrup	40
Fish, dried	35-36	Tenderloins	33
Fish, fresh	20	Tobacco	32-35
Fish, canned	35-40	Vegetables, fresh	34-36
Fruits, dried	35-40	Walnuts	35
Fruits, fresh	32-36	Wheat flour	36-40
Furs	28-35	Wines	40-45

* Compilation from various authorities.

MECHANICAL REFRIGERATION—RATES FROM PRINCIPAL COLD STORAGE HOUSES.

TABLE GENERAL STORAGE.

SUBSTANCE.	CONDITIONS. Kind of Package or Amount.	Best Temperatures.	Fraction of a Month.	First Month.	Each Succeeding Month.	For the Season.	Season Ends.	General Season is from May to May.
Butter	Transient small lots	32° to 38°	½c.	¼c.	⅛c.			Gross weight.
	500 to 1000 pounds	"				⅛c.		Gross weight.
	10,000 pounds	"				¼c.		Gross weight.
	Season rates before the 15th of August	"				1c.	May 1	Gross weight.
	After 15th of August to 1st of October	"				¾c.	May 1	Gross weight.
	After 1st of October	"				½c.	May 1	Gross weight.
	Carried over one season	"				3¾c.		Net weight.
	Carried over two seasons	"				4¾c.		
Cheese	60 pound boxes	33°		12c.				Per box.
	35 pound boxes	"		8c.				Per box.
	18 pound boxes	"		5c.				Per box.
	Per pound	"			¼c.	⅝c.	Dec. 1	Gross weight.
Eggs	30 dozen cases	32° to 34°			15c.			Per case.
	36 dozen cases	"			18c.			Per case.
	Per dozen	"		½c.	½c.	2½c.	April 1	Same rate for part of season.
	In barrels	"			40c.			
Dried fruit	Per flour barrel	36°				$1 25	Nov. 1	
Apples, Peaches	Per sugar barrel	"				1 60		
Pears, Cherries	Sacks per pound	"				⅝c.		Gross weight.
Berries, etc.	Per pound	"		¼c.		¾c.		
Fresh fruit	In boxes	"		5c.				Per cubic foot.
Apples	In lots of 50 barrels and upwards	28° to 32°		20c.		1 00	July 1	
	500 barrels	"		20c.	15c.			
	1000 or over	"			10c.			
Peaches	Per crate			40c.				
Pears	Per barrel			35c.				
Melons	Per barrel			35c.				
Cantaloupes	Per barrel			35c.				
Grapes	Per pound	36°		½c.				
Lemons, Oranges	Per box	55°		25c.		40c.		
	Per case	"				60c.		
Dates and Figs, etc.	Per pound	"		¼c.				
Berries	Per crate, large	36°		35c.				
Berries	Per crate, small			25c.				
Preserves	Per pound			¼c.				
Mince Meat	Per pound			¼c.				

TABLE OF GENERAL STORAGE.—*Concluded.*

SUBSTANCE.	CONDITIONS. Kind of Package or Amount.	Best Temperatures.	Fraction of a Month.	First Month.	Each Succeeding Month.	For the Season	Season Ends.	General Season is from May to May.
Sauer Kraut	Per 33 gal. barrel	32°				$1 00	Nov. 1	
Sauer Kraut	Per 42 gal. barrel					1 25		
Honey, Jelly, etc.	Per pound			¼c.				
Buckwheat	Per barrel	32°				1 25	Nov. 1	
Flour	Per pound in sacks					⅝c.		
Nuts	Per pound			½c.				
Garden truck vegetables	Per pound	36° to 38°		25c.				
Dried Corn	Per flour barrel	32° to 36°				1 25	Nov. 1	
Salt Meat	Per tierce			25 to 35				
	Per barrel			20 to 25				
Dried Beef				35c.				
Lard, etc.	Per pound			¼c.				
Preserves	Per gallon in jugs	33°				5c.		
Syrups	Per gallon in jugs					5c.		
Apple, Peach and Pear Butter	Half barrel					1 00	Dec. 1	
	Per barrel					2 00		
Cider	Per barrel, 33 gal.	30°				1 00		
	Per barrel, 42 gal.					1 25		
Beer	Half barrel	33° to 41°		30c.				
	Quarter barrel	"		15c.				
	Per barrel	"		50c.				
Fresh Meat	Per pound	38°		¼c.				
	Per quarter			25c.	per	month.		
Storage room	Per 1000 cubic feet							$25 and upwards per month.
Veal	Per pound	36°		25c.	per	month.		
Lamb	Per pound			15c.	per	month.		

Foreign and domestic fruits, nuts, ¼c. per month or ¾c. per season; in large lots, ½c. per season.
Other goods than given in table range in quantity ⅝c. per pound gross weight per season ending November 1.

SUBSTANCE.	CONDITIONS. Kind of Package or Amount.	Best Temperatures.	Fraction of a Month.	First Month.	Each Succeeding Month.	For the Season	Season Ends.	General Season is from May to May.
Game		32° to 36°						15c. per season.
Ducks, Grouse, Quail	Per dozen	"						

STORAGE IN FREEZING ROOM BELOW 20°.

SUBSTANCE.	CONDITIONS. Kind of Package or Amount.	Best Temperatures.	Fraction of a Month.	First Month.	Each Succeeding Month.	For the Season	Season Ends.	General Season is from May to May.
Game	Per pound gross							½c. per month.
Venison and Poultry	Per pound gross							½c. per month.
Quails	Per dozen							15c. per season.
Fish		25° to 30°						½c to ¼c. per month.

The above table will serve as a guide until the cost, based on running expenses, to suit your particular trade can be established to suit demand of locality.

CHAPTER III.

COMPARISON OF THERMOMETER SCALES.

FAHRENHEIT AND CENTIGRADE.

Readings for Boiling and Freezing Points.

Reading Fahrenheit.	Difference.	Reading Centigrade.
212°.0	Boiling Point.	100°.0
	180°. F $=$ 100°.0 C.	
32°.0	Freezing Point.	0°.0
	32°.0 F. $= \frac{32.0 \times 9}{5} =$ 17°.77 + C.	
0°.0		—(17.77)

METHODS OF CALCULATION.

To Obtain Equivalent Values for Degrees.

180° F. = 100° C.
18° F. = 10° C.
9° F. = 5° C.
1° F. = $\frac{5}{9}$° C.
$\frac{5}{9}$° F. = 1° C.

IN GENERAL.

a = number of degrees F.
b = number of degrees C.
a° F. = a $\times$ $\frac{5}{9}$° C.
b $\times$ $\frac{9}{5}$° F. = b° C.

[*The next page is numbered* 366. *The error was not noticed until it was too late to correct. The matter, however, is continuous and nothing was omitted.*]

EXAMPLES.

$a = 45°.$

$a° F. = 45° F. = a \times \frac{5}{9}° C. = \frac{45 \times 5}{9}° C. = 25° C.$

$\therefore$ 45° F. = 25° C.

$b = 25°$ C.

$b° C. = 25° C. = b \times \frac{9}{5}° F. = \frac{25 \times 9}{5}° F. = 45° F.$

$\therefore$ 25° C. = 45° F.

To obtain corresponding temperature readings.

To change Reading F. to Reading C. for a given temperature.

(1) Reading F. = Number of degrees F. above 0.0 F.

(2) Reading C. = Number of degrees C. above 0.0 C.

(3) Reading F. — 32 = Number of degrees F. above freezing.

(4) Reading C. = Number of degrees C. above freezing.

(5) $\frac{(\text{Reading F.} - 32) \times 5}{9}$ = Number of degrees C. above freezing.

Therefore from (4),

(6) $\frac{(\text{Reading F.} - 32) \times 5}{9}$ = Reading C.

To change Reading C. to Reading F. for a Given Temperature.

(7) Reading C. = Number of degrees C. above 0.0 C.

(8) Reading C. = Number of degrees C. above freezing.

(9) $\frac{\text{Reading C.} \times 9}{5}$ = Number of degrees F. above freezing.

(10) $\frac{\text{Reading C.} \times 9}{5} + 32$ = Number of degrees F. above 0.0° F.

Therefore from (1),

(11) $\frac{\text{Reading C.} \times 9}{5} + 32$ = Reading F.

EXAMPLES.

Reading F. = 77° F.

$\frac{(\text{Reading F.} - 32) \times 5}{9} = \frac{(77 - 32) \times 5}{9} = \frac{45 \times 5}{9} = 25° C.$

$\therefore$ Reading 77° F. = Reading 25° C.

Reading C. = 25° C.

$$\frac{\text{Reading C.} \times 9}{5} + 32 = \frac{25 \times 9}{5} + 32 = 45 + 32 = 77.$$

⁂ Reading 25° C. = Reading 77° F.

Caution: Note difference between simply degrees and reading in degrees.

For instance, 45° F. = 25° C.

But reading, 77° F. = reading 25° C.

CHAPTER IV.

AUXILIARY APPARATUS.

ICE CANS.

Ice cans are commonly made of heavy galvanized iron, riveted and soldered, with the top reinforced with a band of same. In larger sizes, the bottom is sometimes made heavier than the sides.

The general shape of the can is rectangular, with about one-eighth inch taper per foot in depth, the bottom being smaller than the top. This feature is, of course, to permit the block of ice to readily slip out from the can after it has been loosened from the sides by the application of warm or tepid water to the outside of the can. The depth is generally two or more times as great as any of the other dimensions.

The amount of ice per can will depend, of course, upon the depth to which the cans are filled. Whether this depth shall be even tolerably regular or not, depends upon the methods that are observed in regard to the filling. Methods can be employed that will give quite uniform results.

The time of freezing will, of course, depend upon the temperature of the water to be frozen and the temperature of the brine.

Details of standard cans are given on page 49 and 50, in Part I, Chapter V, on ice-making.

HOISTS AND TRAVELING CRANES.

It is needless to say that there is an extended variety of apparatus in the line of hoists and traveling cranes on the market. Nor is it necessary to enlarge on the utility of such apparatus. How much apparatus along this line shall be installed, is a matter of individual consideration. The cases are

rare, indeed, where they are installed in which they do not, in a short space of time, establish themselves as an indispensible adjunct to the plant.

Certainly the ideal method of handling the frozen product is to raise the can with the ice by means of a hoist suspended from a traveler, carry it along by means of the traveler, and deposit it to the ice dump directly.

ICE DUMP.

The ideal ice dump will receive the can with the ice from the crane, tip so that the ice is ready to slip out when its hold to the sides of the can has been released, will turn on the warm or tepid water automatically, arranged to properly spray the can so as to most efficiently thaw the ice holding to the walls of the can, and after the ice has slipped out, will turn back to the original position and at the same time automatically turn off the water.

A refinement in details is found in the method of carrying off the flow of water, and in design to combine neatness with efficiency and reliability.

FILLING CANS.

The matter of filling cans is one of those practical matters connected with an ice plant that, if properly planned and provided for, will run along smoothly and seem to take care of itself, or will, in the contrary case, give trouble.

Among the troubles may be mentioned overflowing the can, with the consequent weakening of the brine. Overflowing of the brine tank may cause damage to the insulating material of the tank. A properly arranged overflow outlet will prevent the moistening of the insulation.

FLOAT DEVICE.

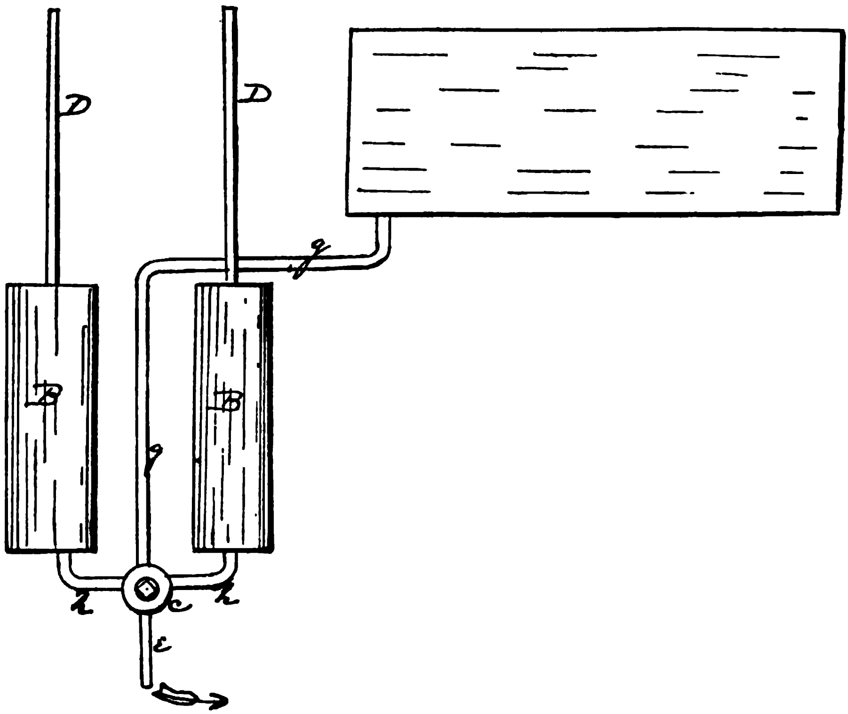
Automatic can fillers are on the market that are reliable, and pay for themselves in a very short time. The automatic feature consists in a float arranged to shut off the water when the can is filled to the depth desired. Thus a uniformity in

the level of the water is obtained, and in case the cans are of the same dimensions, the cakes of ice will be of practically uniform size and weight.

WALL DEVICE.

An arrangement that is simple and reliable for preventing an over-supply of water to the can and at the same time ensuring a uniform amount of water per can, is shown in Fig. 192.

FIG. 192.



CAN-FILLING DEVICE.

The same consists in an apparatus bolted against the wall, used in connection with a storage tank for storing the water to be used for the ice-tank supply.

The arrangements referred to consists of two round galvanized iron tanks B, B, each tank holding practically the amount of water necessary for the supply to a can. These tanks are

connected by a special four-way cock, so designed as to allow the water coming from the storage tank A to enter and fill one tank, while the water is flowing out of the other to the can.

The pipe E conducts the water through a hose to the can being filled. Pipe G is the connection between the storage and the filling tanks.

Pipes D, D are small ⅜-inch pipes, open at the top and extending to the height of the top of the storage tank. These apparently insignificant features are more important than may at first appear to be the case. For while they afford outlets for the air to escape that is displaced by the water, they at the same time serve to regulate the quantity of water for each supply. As they extend above the level of the water in the tank, the level of the water in the tank will limit the supply in each case. On account of the small bore of the pipe, differences in quantity, due to differences in the level of the water in the tank, will be inappreciable.

A small rope, one-half inch in diameter, running along the side of the freezing tanks, is connected so that a pull either way will throw the handle of the cock C. When one can supply is run out, no more water will run until the rope is pulled, throwing the cock lever.

FILTERS AND FILTRATION.

The place of a good filter in an ice-making plant is well established, The objections to foreign matter in ice are due to the inherent objectionable qualities of such foreign matter, and also to the fact that its presence results in a discoloration of the ice.

Red core and other discolorations in ice are due to the presence of iron rust, oil, dust, and other foreign matters. The function of a filter is to remove all such foreign matter from the water before freezing.

THE INTERNATIONAL FILTER.

The International Filter, shown in Figs. 193 and 194, com-

mends itself for its simplicity and effectiveness. The filter-body consists of two shells, which are hinged together, and clamped around the edge by means of hand bolts. This filter-body is mounted on an independent pedestal, which may be removed in the event of insufficient fall of water, so that the filter can be used in a very narrow range of height.

The filtering is accomplished by means of filter discs, locked

FIG. 193.

THE INTERNATIONAL FILTER

securely between the two shells. The inlet is in the lower shell, while the outlet is in the upper one. Accordingly, all the water must pass through the filter discs, as there is no way for it to pass around them.

The upward filtration is particularly advantageous, as the heavy particles tend to fall away from the filter discs instead of clogging them.

Filter discs of special cloth are used, which will arrest rust, congealed oil, etc., in the distilled water. In cases where the rust or other foreign matter is very finely divided, or where

natural water is used, filter discs of pure compressed cotton fibre are used in addition to the special cloths.

The compressed cotton fibre discs are very inexpensive and are discarded when clogged, while the special cloth discs are used indefinitely, being washed before re-using.

FIG. 194.

THE INTERNATIONAL FILTER: OPENED FOR CHANGING FILTERING CLOTHS.

The water can be shut off, the filter opened, the discs changed, and the filter closed and put in operation again inside of two minutes.

DIRECTIONS FOR USING THE INTERNATIONAL FILTER.

Open filter, place on lower screen two of the special cloth discs, close filter and lock tightly.

When the flow of water becomes slow, (an indication that the discs are clogged), close inlet, open the faucet at bottom and the air cock on top of filter, open the filter, remove the lower disc and replace with a fresh one on top. Close the filter and it is again ready for use.

If the water contains large quantities of rust or other very fine particles, use one of the compressed cotton fibre discs, in addition to the special cloth discs, placing it between same.

The cloth discs when clogged must be thoroughly washed, and can be used indefinitely.

When in changing the special cloth disc the compressed cotton fibre disc is found to be clogged, discard same and replace with a fresh one.

The filter should be placed after the storage tank, and as close as possible to the filling hose, so that there can be no opportunity for subsequent contamination.

From two to three pounds pressure is sufficient to operate the filter.

Where there is practically no difference in height between the water level in the storage tank and the top of the ice cans, a pump with regulator attachment may be used. Cases of this kind are rare, and are dealt with specially.

If the required elevation is not available, the filter may be removed from the pedestal and placed directly upon the freezing tank or on the floor beside same.

When using the filter for distilled water for bottling, compressed cotton fibre discs are used in place of the special cloths. When the lower compressed cotton fibre disc is clogged, it is removed, discarded and replaced with a fresh one on top.

CONSTRUCTION.

The International Filter is made of iron, heavily galvanized, with brass fittings and trimmings, and of high-grade brass, block-tinned throughout. The fittings are all of standard sizes.

The filter is manufactured in four different sizes, with capacities as shown in table given below:

	Capacity.	
Filter.	Gallons of water per hour.	Tons of ice per day.
Number 0	75	3 to 5
Number 1	150	12 to 18
Number 2	500	35 to 50
Number 5	1100	70 to 100

AMMONIA DISTILLER AND PURIFIER.

This apparatus, when installed in connection with a refrigerating or ice-making plant, enables the operator to re-distill the entire charge of ammonia without withdrawing it from the system and without interfering for one moment with the continuous operation of the plant. If used regularly, in the usual operation of the plant, it keeps the ammonia at all times in a perfectly pure and anhydrous condition, a condition impossible to attain without its use, and one which is absolutely essential to the obtaining of the highest efficiency from a refrigerating machine.

The liquid ammonia with its impurities is let into the distiller from the liquid receiver, oil trap, or direct from the condenser, through the liquid inlet A. Fig. 195. The inlet valve should be left open until the glass gauge shows that the reservoir is slightly more than half full. The ammonia, relieved of the pressure which has until now kept it in the form of a liquid, begins to expand into a gaseous form, the horizontal position of the apparatus affording, when the reservoir is half full, an evaporating surface of over six square feet.

The ammonia vapor passes out through the pipe B into the liquid trap which is designed to prevent the possibility of any liquid being carried over into the compressor. This trap is connected by the pipe C with the suction line to the compressor. In order to accelerate the vaporizing of the ammonia, a steam pipe is provided for raising the temperature in the distilling apparatus. The steam enters through the pipe D. which, as will be seen, is inserted in another and larger pipe. A drain, marked E, is provided for taking care of the water of condensation.

Care should be taken that the temperature of the liquid is not raised above 60 to 70 degrees Fahrenheit, and to this end the pressure recorded on the pressure gauge should not be allowed to go above 90 to 100 pounds. The temperature corresponding to a pressure of 90 pounds is approximately 60 degrees, and that is high enough to make the evaporation quite rapid and at the same time is low enough to preclude the vaporizing of any oil or water contained in the liquid ammonia. By observing the pressure gauge at the end of the apparatus, the operator can tell when the operation is complete and when all of the liquid which will evaporate has been vaporized. The outlet valve F on the suction line of the compressor should be left open until the pressure in the reservoir is reduced to that existing in the suction line to the machine, as indicated by the low-pressure gauge in the engine-room.

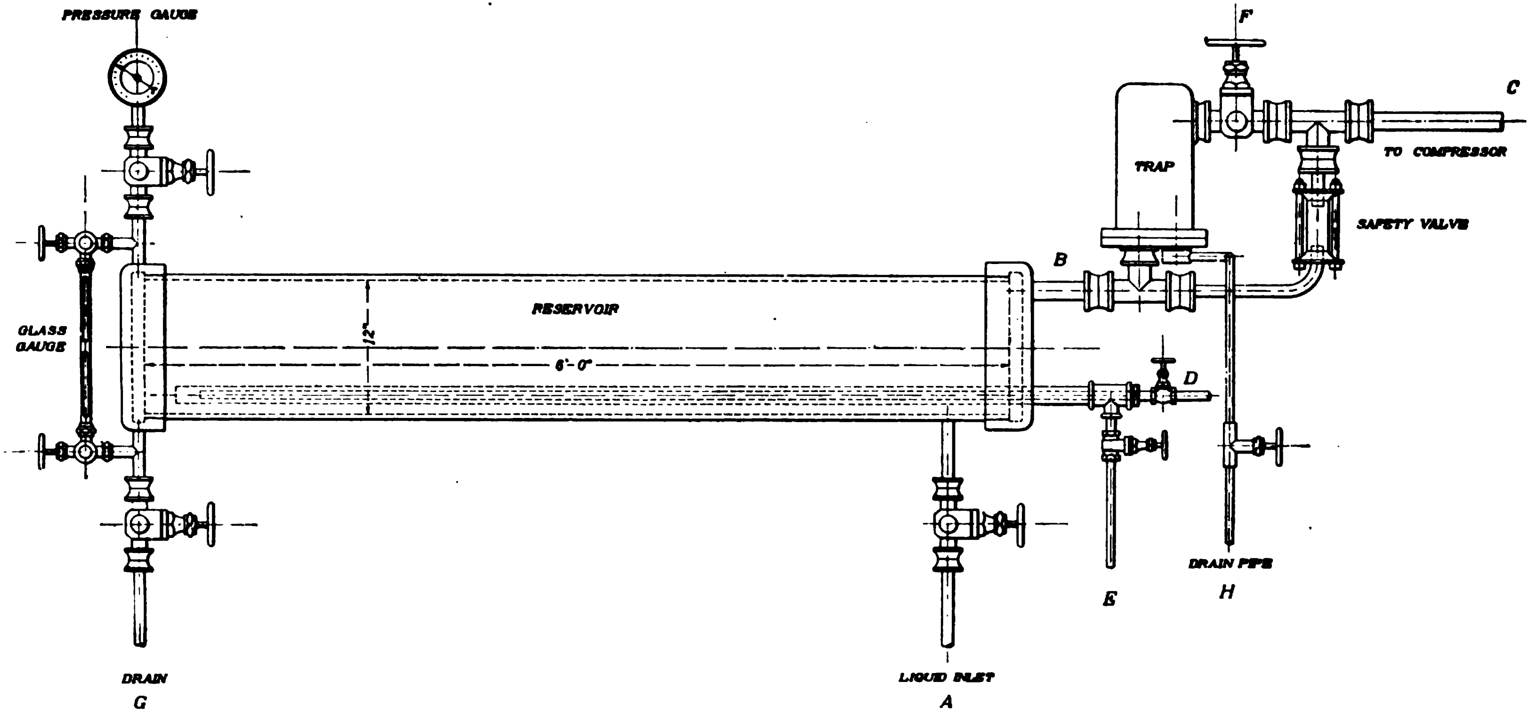
The valve F should then be closed and the remaining liquid, consisting of oil, water and other impurities, discharged from the apparatus through the drain pipe G, which, it will be observed, is placed at the lowest point of the head. A drain, marked H, is provided for draining the liquid trap of any impurities that may have been carried along with the vapor from the reservoir of the apparatus. A safety valve is provided in a by-pass around the liquid trap so that in the event that the valves are not properly opened to relieve the pressure, there will be no danger of accidents.

This apparatus is substantially made and will outlast almost any other part of the apparatus used in connection with a refrigerating plant. Its cost is very slight indeed when compared with the many advantages to be derived from always having the ammonia in a pure, anhydrous condition, and thus being at all times able to get the maximum efficiency from the plant.

The references given above apply to Fig. 195, which shows the apparatus in elevation.

Fig. 195.

AMMONIA DISTILLER & PURIFIER.



(To face page 376.)

ATTEMPERATORS.

FLAT COIL TYPE.

This type of attemperator is illustrated in Figs. 196 and 197. A plan view is shown in Fig. 196, while in Fig. 197 is shown an elevation with a section of the vat removed. These attemperators are made of extra-heavy pipe. They are suspended from the top of the vats.

FIG. 196.

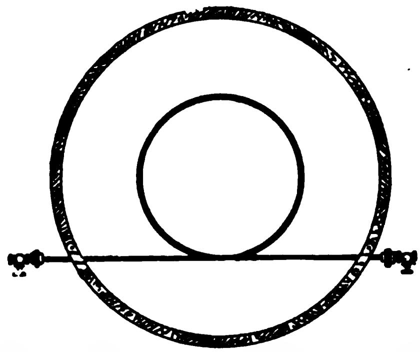
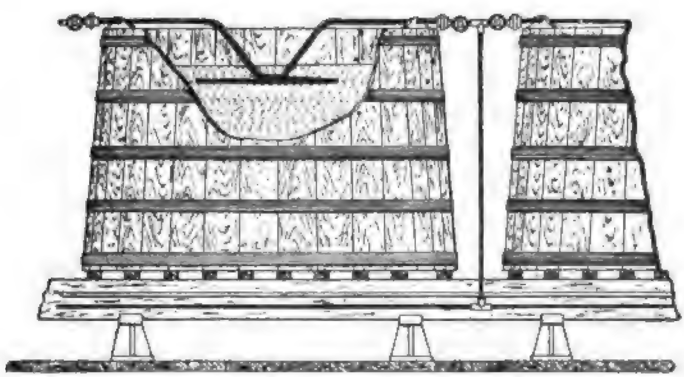


FIG. 197.



FLAT COIL ATTEMPERATOR.

They can be arranged stationary, or may be provided with swivel joints, so that they can be swung up out of the vat.

They are made of 1¼, 1½ and 2-inch iron pipe ordinarily,

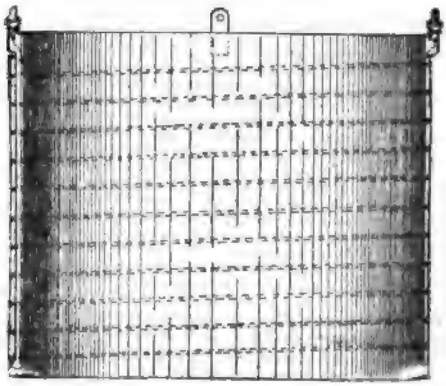
though brass or copper may be used. The diameter of the coil is made to suit the dimensions of the fermenting tubs.

Other examples are shown in Figs. 16, 17 and 18 (Boyle) and Fig. 15 (Eclipse), the latter showing a complete system.

WOLF CYLINDRICAL ATTEMPERATOR.

In Figs. 198 and 19, page 34, are shown illustrations of the Wolf patent attemperator. Fig. 198 shows a view of the attemperator alone, while Fig. 19 shows the attemperator in position with a section of the vat removed. The attemperator is supported by cord, attached at three points,

FIG. 198.



CYLINDRICAL ATTEMPERATOR.

which unite and pass over a pulley overhead, by means of which it can be raised or lowered as desired. To permit this to be done, the connections with the pipe mains for the circulating medium are made flexible.

This attemperator is an improvement over the flat coil type. It is made of planished and tinned heavy copper, or galvanized iron, and has a large cooling surface in proportion to its weight. It consists of two hollow cylinders, put together so as to form one cylinder with hollow walls. Between these walls are wires or strips following a helical course, leading from the supply to the discharge pipe, as shown by the dotted lines in

Fig. 198. The cooling water accordingly follows a winding course in its passage, and cools the liquid contents of the vat in contact with both the inside and the outside of the cylinder.

This type of attemperator is made in two sizes, the data in regard to which are as follows:

Diameter.	Height.	Cooling surface.	Diameter of equivalent iron coil.
18 inches ×	18 inches.	14¼ square feet.	10 feet.
36 inches ×	30 inches.	47 square feet.	34 feet.

CHAPTER V.

TABLES ON AMMONIA AND COMPRESSOR CAPACITY.

CAPACITY OF MACHINES AND WATER CONSUMPTION FOR AMMONIA COMPRESSION SYSTEMS.

We give below a few average values, based upon the requirements for the ammonia compression system.

Horse-power Required.	Capacity of Machine in tons per 24 hours.		Quantity of Water.
	Ice-melting.	Ice-making.	Gallons per hour.
10	5.0	2.5	480
15	10 0	5.7	960
20	15.0	8.8	1.440
30	23.7	14.4	2,400
40	32.0	19.3	3,100
50	40.4	24.5	3,800
60	48.6	29.6	4,050
75	60.7	37.1	4,950
100	81.5	61.4	5,700
150	125.0	79.0	7,800
200	170.0	105.0	9,600
300	256.0	158.0	12,400
400	343.0	210.0	15,000
500	430.0	260.0	17,700

PROPERTIES OF SATURATED AMMONIA.

(WOOD-DAVIDSON.)

Temperature.		Pressure.		Heat of Vaporization.			Weight per cubic foot.	
Fahrenheit degrees.		Pounds per square inch.		Thermal Units.			Pounds.	
Scale.	Absolute.	Absolute.	Gauge.	Latent or Internal.	Sensible or External.	Total.	Vapor.	Liquid.
t	T	p	p_1	L_1	L_{11}	L	w_1	w_2
—40	420.66	10.69	—4.01	531.44	48.23	579.67	.0410	42.589
—35	425.66	12.31	—2.39	528.44	48.48	576.68	.0469	42.338
—30	430.66	14.13	—0.57	524.92	48.77	573.69	.0535	42.123
—25	435.66	16.17	+1.47	521.62	49.06	570.68	.0608	41.858
—20	440.66	18.45	3.75	518.29	49.38	567.67	.0690	41 615
—15	445.66	20.99	6.29	514.97	49.67	564.64	.0779	41.374
—10	450.66	23.80	9.10	511.62	49.99	561.61	.0878	41.135
—5	455.66	26.92	12.22	508.25	50.31	558.56	.0988	40.900
0	460.66	30.37	15.67	504.82	50.68	555.50	.1107	40.650
+5	465.66	34.16	19.46	501.59	50.84	552.43	.1240	40.404
10	470.66	38.34	23.64	498.22	51.13	549.65	.1383	40.160
15	475.66	42.94	28.24	494.93	51.33	546.26	.1541	39.920
20	480.66	47.95	33.25	491.54	51.61	543.15	.1711	39.682
25	485.66	53.43	38.73	488.23	51.80	540.00	.1897	39.432
30	490.66	59.42	44.72	484.91	52.01	536.91	.2099	39.200
35	495.66	65.92	51.22	481.56	52 22	533.78	.2318	38.940
40	500.66	72.99	58 29	478.21	52.42	530.63	.2554	38.684
45	505.66	80.66	65.96	474.85	52.62	527.47	.2809	38.461
50	510.66	88.96	74.26	471.48	52.82	524.30	.3084	38.226
55	515.66	97.92	83.22	468.11	53.01	521.12	.3380	37.994
60	520.66	107.59	92.80	464.72	53.21	517.93	.3697	37.736
65	525.66	118.03	103.33	461.35	53.38	514.73	.4039	37.481
70	530.66	129.19	114.49	457.85	53.57	511.52	.4401	37.230
75	535.66	141.22	127.52	454.23	53.76	508.29	.4791	36.995
80	540.66	154.10	139.40	450.70	53.96	505.05	.5205	36.751
85	545.66	167.88	153.18	447.66	54.15	501.81	.5649	36.509
90	550.66	182.62	167.92	443.83	54.28	498.55	.6120	36.258
95	555.66	198.35	183.65	440.88	54.41	495 29	.6622	36.023
100	560.66	215.12	200.42	436.96	54.54	492.01	.7153	35.778
105	565.66	232.98	218.28	434.08	54.67	488.72	.7757	
110	570.66	251.97	237.27	430.64	54.78	485.42	.8312	
115	575.66	272.14	258.74	427.40	54.91	482.41	.8912	
120	580.66	293.49	275.79	423.75	55.03	478.79	.9608	
125	585.66	316.16	301.46	420.39	55.09	475.45	1.0310	
130	590.66	340.42	325.72	416.94	55.16	472.11	1.1048	
135	595.66	365.16	350.46	413.53	55.22	468.75	1.1824	
140	600.66	392.22	377.52	410.09	55.29	465.39	1.2642	
145	605.66	420.49	405.79	406.67	55.34	462.01	1.3497	
150	610.66	450.20	435.50	402.23	55.39	458.62	1.4396	
155	615.66	481.54	466.84	399.79	55.43	455.22	1.5358	

CUBIC FEET OF AMMONIA GAS PER MINUTE TO PRODUCE ONE TON OF REFRIGERATION PER DAY.

CONDENSER.

		P	103	115	127	139	153	168	185	200	218
	p	t	65°	70°	75°	80°	85°	90°	95°	100°	105°
REFRIGERATOR.	4	—20°	5.84	5.9	5.96	6.03	6.06	6.16	6.23	6.30	6.43
	6	—15°	5.35	5.4	5.46	5.52	5.58	5 64	5.70	5.77	5.83
	9	—10°	4.66	4.73	4.76	4.81	4.86	4.91	4.97	5.05	5.08
	13	— 5°	4.09	4.12	4.17	4.21	4.25	4.30	4.35	4.40	4.44
	16	0°	3.59	3.63	3.66	3.70	3.74	3.78	3.83	3.87	3.91
	20	5°	3.20	3.24	3.27	3.30	3.34	3.38	3.41	3.45	3.49
	24	10°	2.87	2.9	2.93	2.96	2 99	8.02	3.06	3.09	3.12
	28	15°	2.59	2.61	2.65	2.68	2.71	2.73	2.76	2.80	2 82
	33	20°	2 31	2.34	2.36	2.38	2.41	2.44	2.46	2.49	2.51
	39	25°	2.06	2.08	2.10	2.12	2.15	2.17	2.20	2.22	2.24
	45	30°	1.85	1.87	1.89	1.91	1.93	1.95	1.97	2.00	2.01
	51	35°	1.70	1.72	1.74	1.76	1.77	1.79	1.81	1.83	1.85

SOLUBILITY OF GASES IN WATER.

SOLUBILITY OF GASES IN WATER AT ATMOSPHERIC PRESSURE.

1 Vol. Water dissolves Vols. Gas.	32° Fahr.	39.2° Fahr.	50° Fahr.	60° Fahr.	70° Fahr.
Air	.0247	.0224	.0195	.0179	.0171
Ammonia	1049 6	941.9	812 8	727 2	654.0
Carbon Dioxide . .	1.7987	1.5126	1.1847	1.0020	.9014
Sulphur Dioxide . .	79.789	69.828	56.647	47.276	39.374
Marsh Gas	.0545	.0499	.0437	.0391	.0350
Nitrogen	.0204	.0184	.0161	.0148	.0140
Hydrogen	.0193	.0193	.0191	.0193	.0193
Oxygen	.0411	.0372	.0325	.0299	.0284

HORSE POWER PER TON OF REFRIGERATION.

CONDENSER PRESSURE AND TEMPERATURE.

REFRIGERATOR PRESSURE AND TEMP.

p	p / t	103 / 65°	115 / 70°	127 / 75°	139 / 80°	153 / 85°	168 / 90°	184 / 95°	200 / 100°	218 / 105°
4	−20°	1.0584	1.1304	1.2051	1.2832	1.3611	1.4427	1.5251	1.6090	1.6910
6	−15°	.9972	1.0692	1.1450	1.2221	1.3001	1.4101	1.4609	1 5458	1.7800
9	−10°	.9026	.9777	1.0453	1.1183	1 1926	1.2602	1.3471	1.4352	1.5098
13	−5°	.8184	.8833	.9537	1.0230	1.0935	1.1679	1.2467	1.3209	1.3964
16	0°	.73 2	.8008	.8618	.9328	1.0019	1.0718	1.1467	1.2194	1.2547
20	5°	.6665	.7312	.7946	.8593	.9278	.9978	1.0656	1.1381	1.2121
24	10°	.5915	.6629	.7257	.7894	.8545	.9205	.9911	1.0595	1.1294
28	15°	.5410	.5998	.6641	.7276	.7924	.8553	.9224	.9943	1.0608
33	20°	.4745	.5340	.5923	.6716	.7148	.7796	.8420	.9031	.9736
39	25°	.4103	.4659	.5227	.5804	.5992	.7022	.7667	.8289	.8922
45	30°	.3509	.4056	.4612	.5178	.5755	.6353	.6944	.7590	.8172
51	35°	.3005	.3546	.4101	.4666	.5214	.5804	.6398	.7009	.7629

HORSE POWER REQUIRED TO COMPRESS ONE CUBIC FOOT OF AMMONIA PER MINUTE.

CONDENSER PRESSURE AND TEMPERATURE.

REFRIGERATOR PRESSURE AND TEMP.

p	p / t	103 / 65°	115 / 70°	127 / 75°	139 / 80°	153 / 85°	168 / 90°	184 / 95°	200 / 100°	218 / 105°
4	−20°	.1809	.1916	.2022	.2128	.2235	.2342	.2048	.2554	.2661
6	−15°	.1864	.1980	.20·7	.2214	.2330	.2447	.2563	.2679	.2796
9	−10°	.1937	.2067	.2196	.23 5	.2454	.2583	.2712	.2842	.2971
13	−5°	.2001	.2144	.2287	.2430	.2578	.2716	.2859	.30 2	.3145
16	0°	.2948	.2206	.2363	.2521	.2679	.2836	.2994	.3151	.3309
20	5°	.2083	.2257	.2430	.2604	.2778	.2952	.3125	.3296	.3173
24	10°	.2096	.2286	.2477	.2667	.2858	.3048	.3239	.3429	.3620
28	15°	.2089	.2298	.2506	.2715	.29 4	.3133	.3342	.3551	.3760
33	20°	.2054	.2282	.2510	.2738	.2 66	.0195	.3323	.3651	.3879
39	25°	.1992	.2240	.2489	.2738	.2987	.3238	.3485	.3734	.3983
45	30°	.1897	.2169	.2440	.2711	.29·2	.3253	.3524	.3795	.4066
51	35°	.1768	.2062	.2357	.2651	.2946	.3241	.3535	.3830	.4124

NOTE.—These figures do not allow for friction.

TABLE SHOWING REFRIGERATING EFFECT OF ONE CUBIC FOOT OF AMMONIA GAS AT DIFFERENT CONDENSER AND SUCTION (BACK) PRESSURES IN B. T. UNITS.

Temperature of Gas in Degrees F.	Corresponding Suction Pressure, Lbs. per sq. in.	Temperature of the Liquid in Degrees F.								
		65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (gauge), lbs. per sq. in.								
		103	115	127	139	153	168	184	200	218
	G. Pres.									
—27°	1	27.30	27.01	26.73	26.44	26.16	25.87	25.59	25.30	25.02
—20°	4	33.74	33.40	33.04	32.70	32.34	31.99	31.64	31.30	30.94
—15°	6	36.36	36.48	36.10	35.72	35.34	34.96	34.58	34.20	33.82
—10°	9	42.28	41.84	41.41	40 97	40.54	40.10	39.67	39.23	38.80
—5°	13	48.31	47.81	47.32	46.82	46.33	45.83	45.34	44.84	44.35
0°	16	54.88	54.32	53.76	53.20	53.64	52.08	51.52	50.96	50.40
5°	20	61.50	60.87	60.25	59.62	59.00	58.37	57.75	57.12	56.50
10°	24	68.66	67.97	67.27	66.58	65.88	65.19	64.49	63.80	63.10
15°	28	75.88	75.12	74.35	73.59	72.82	72.06	71.29	70.53	69.76
20°	33	85.15	84.30	83.44	82.59	81.73	80.88	80.02	79.17	78.31
25°	39	95.50	94.54	93.58	92.63	91.68	90.72	89.97	88.81	87.86
30°	45	106.21	105.15	104.09	103.03	101.97	100.91	99.85	98.79	97 73
35°	51	115.69	114.54	123.39	112.24	111.09	109.94	108.79	107.64	106.49

TABLE GIVING NUMBER OF CUBIC FEET OF GAS THAT MUST BE PUMPED PER MINUTE AT DIFFERENT CONDENSER AND SUCTION PRESSURES, TO PRODUCE ONE TON OF REFRIGERATION IN TWENTY-FOUR HOURS.

Temperature of Gas in Degrees F.	Corresponding Suction Pressure, Lbs. per sq. in.	Temperature of the Gas in Degrees F.								
		65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (gauge), lbs. per sq. in.								
		103	115	127	139	153	168	184	200	218
	G. Pres.									
—27°	1	7.22	7.3	7.37	7.46	7.54	7.62	7.70	7.79	7.88
—20°	4	5.84	5.9	5.96	6.03	6.09	6.16	6.23	6.30	6.43
—15°	6	5.35	5.4	5.46	5.52	5.58	5.64	5.70	5.77	5.83
—10°	9	4.66	4.73	4.76	4.81	4.86	4.91	4.97	5.05	5.08
—5°	13	4.09	4.12	4.17	4.21	4.25	4.30	4 35	4.40	4 44
0°	16	3.59	3.63	3.66	3.70	3.74	3.78	3.83	3.87	3.91
5°	20	3.20	3.24	3.27	3.30	3.34	3.38	3.41	3.45	3.49
10°	24	2.87	2.9	2.93	2.96	2.99	3.02	3.06	3.09	3.12
15°	28	2.59	2.61	2 65	2.68	2.71	2.73	2.76	2.80	2.82
20°	33	2.31	2.34	2.36	2.38	2.41	2.44	2.46	2.49	2.51
25°	39	2.06	2.08	2.10	2.12	2.15	2.17	2.20	2.22	2.24
30°	45	1.85	1.87	1.89	1.91	1.93	1.95	1.97	2.00	2.01
35°	51	1.70	1.72	1.74	1.76	1.77	1.79	1.81	1.83	1.85

CHAPTER VI.

CHARGING AMMONIA COMPRESSION PLANT.

Under this head may be included the charging of a new plant or a plant from which the ammonia has been evacuated, and the adding to the charge of a plant already in operation to make up for deficiencies and losses. The former may be considered under the title of *supplying the first charge,* and the latter under the title of *supplying additional charge.*

SUPPLYING THE FIRST CHARGE.

After the apparatus has been all put together and the process of charging is to be taken up, the first operation should consist in pumping air into the entire system to a high pressure, say 500 pounds per square inch, and testing the system for leaks at this pressure.

After being satisfied that the pressure is maintained satisfactorily and the indications are that the system has no leaks, the air should be pumped out and as good a vacuum as possible should be obtained.

Ammonia gas should now be admitted to the system from a supply tank until a pressure of about one atmosphere is obtained. The system is now filled with a mixture of ammonia gas and the remnant of air that was not pumped out. By pumping out this mixture until a good vacuum is again obtained and re-admitting ammonia gas, the amount of air remaining in the system will be reduced to a minimum. This condition is obtained of course at the sacrifice of some ammonia gas.

Specific directions are given in detail below.

SUPPLYING ADDITIONAL CHARGE.

In the handling of the supply tank for charging a plant with anhydrous ammonia the first step to be taken is to weigh

the tank with the gas. The net weight of the ammonia in a standard tank would be from 100 to 110 pounds.

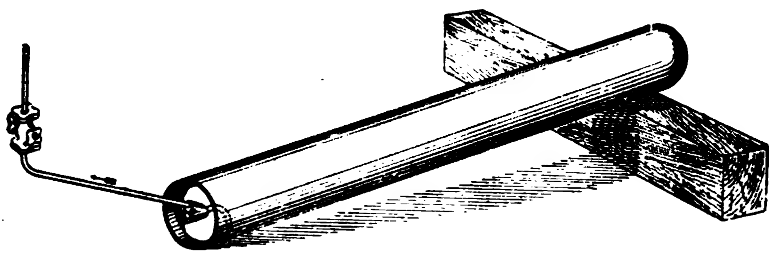
After weighing, the tank should be placed in position for emptying. This means in the first place to raise the closed end about twelve to fifteen inches higher than the other, by blocking the same up. Further, for convenience, the opening for the outlet valve should point upwards. See Fig. 199.

The size of the connecting pipe between the outlet valve of the tank and the inlet valve of the system should be ⅜ inch.

When the connections are made they should be tested by opening the valve cautiously.

If the connections prove to be tight the valve may be fully opened, and the machine started and kept running at a slow

FIG. 199.



POSITION OF TANK TO BE EMPTIED.

rate until the tank is empty. The appearance of frost on the surface of the tank indicates that the tank is nearly empty.

The operation is finished when the suction gauge indicates that atmospheric pressure has been reached and is not changed when the machine is stopped. If the pressure rises the machine should be started up again and run until such will not be the case when it is again stopped. After emptying, close first the valve on the tank and then the inlet valve of the system before disconnecting. At the last stage in the process weigh the tank.

SPECIFIC DIRECTIONS FOR SUPPLYING FIRST CHARGE.

Upon completion of the erecting of an ice-making plant we

find an engine with gas pumps attached for pumping the ammonia gas, the pump being not unlike air compressors; also a system of pipe work attached to both the discharge and suction side of the gas pump. See Fig. 200.

This system is complete within itself, with three openings left to the atmosphere.

The first of these three is a charging connection for permitting ammonia gas to enter from the charging tank K.

The second, on the top of the condensing system at its highest point J, is for removing air which may from time to time enter while making changes in the ammonia system.

The third is usually at the lowest point in the system O connected to the trap E, attached to the refrigerating pipe system D for the removal of oil, water or dirt which may collect in the same.

On the completion of the plant, the connections at the discharge and suction side of the gas compressor should be opened and the engine and compressor run until you are satisfied they are in working order.

When the engine and compressors work smoothly, close up the flange connection on the discharge at F, also the gas valve at N, leaving connections at H open. This allows the pumps to draw in air, and an air pressure to accumulate in the piping.

The object in this accumulating of air pressure is to test joints for leaks.

If no leaks are found, pump air pressure to about 100 lbs. per square inch, then stop until the heat generated in the compression of the air, which will raise the temperature to about 150 degrees F., has passed away.

While your engine is stopped, make a careful examination for leaks, as it is absolutely necessary to have tight pipe work, for the loss of ammonia gas means the loss of ability to do refrigerating.

After allowing the machine to lie still about one hour, start up again and pump up pressure to 200 lbs. per square inch, and again allow the machine to cool down. Continue this

method of pumping pressures until you have a pressure of 500 lbs. per square inch, when the suction flange H should be bolted tight and the valve N opened. This will give you a pressure of, say 450 lbs., on all sides of the gas pump. At this time it will be found that the stuffing-box leaks a large amount of air.

As soon as you definitely determine that all joints around the compressor are tight, shut off the suction and discharge valves N and M, and allow the pressure to remain in the piping. The object of closing the two valves is to prevent the loss of air around the piston and stuffing-box.

The air pressure in the piping will fall as the air becomes cooled, or falling from a temperature of 100 degrees to 70 degrees F., pressure should fall about 23 lbs. per square inch providing there are no leaks in the piping or joints.

While pumping a pressure on the coils, the return pressure gauge R must be closed off at cock 4. These gauges are usually of the class known as a combination gauge, recording both pressure and vacuum; in other words marking the condition from absolute pressure, which means the absence of atmospheric pressure.

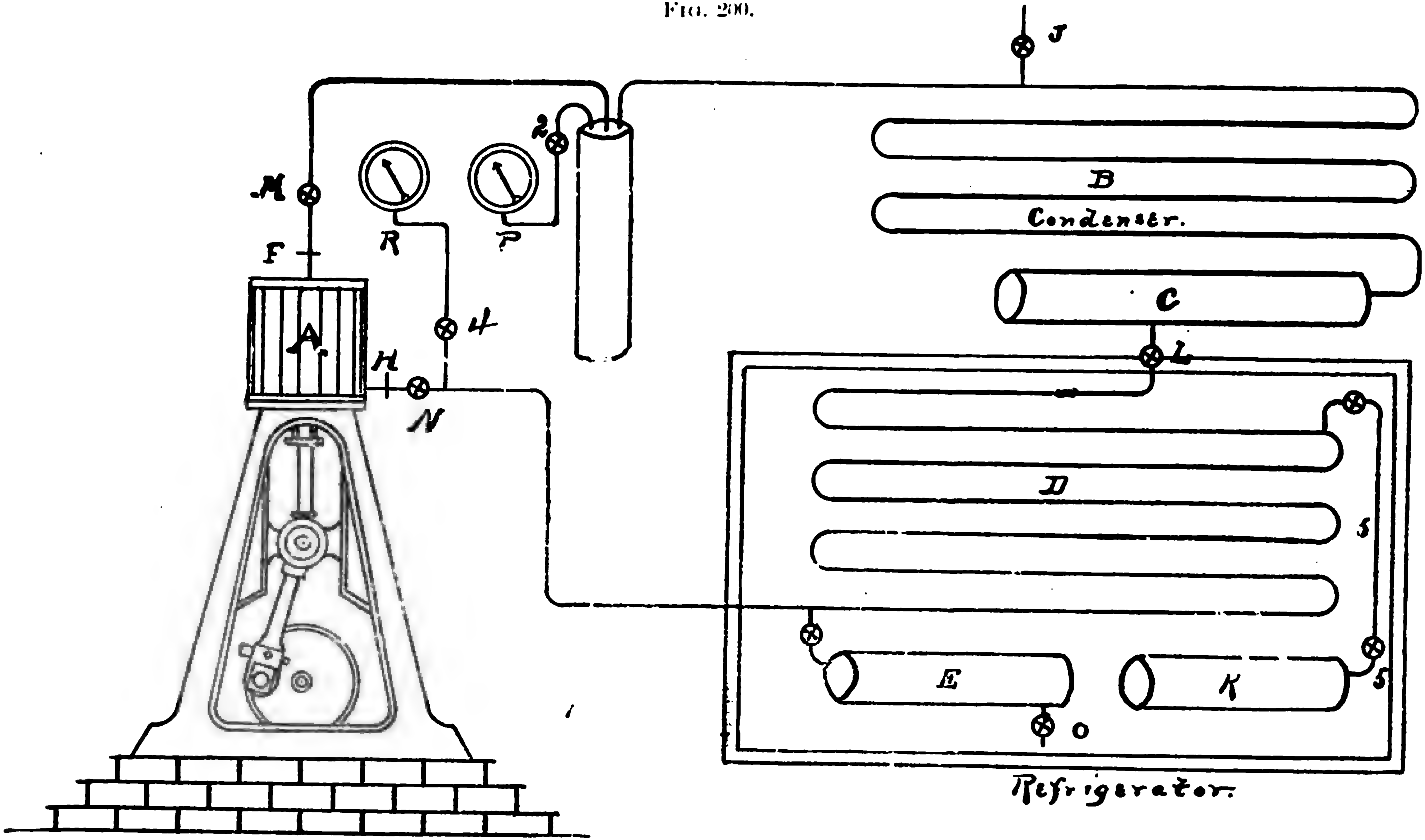
The high pressure can be noted on the gauge P, which is usually constructed to permit the indication of pressures as high as 500 or 600 lbs. per square inch.

If the system is found to be tight, pump the air out of the piping. Close the cock M on the discharge side of the gas pump and open the flange F, which will permit the discharge of the air. Open the valve N on the suction side and permit the air pressure to discharge.

When the pressure is at atmosphere, open the return pressure gauge R and close off the direct pressure gauge by closing cock 2. The reason for shutting off this last gauge is that it does not register below atmosphere, so that if it is not done the interior mechanism of the gauge will be injured.

Start the gas pumps and discharge the air at flange F. Care must be taken in doing this, for if any oil is discharged with air, which comes out in a spray like a fog, and it should

Fig. 200.



(p. 389.) STARTING AN AMMONIA PLANT.

come in contact with the light of a candle or of gas, there would be a sharp explosion, caused by the carbon of the oil mixing with the oxygen of the air and other elements, and result in much damage.

Having pumped the air from the pipes until the combination or back pressure gauge R registers 26 or 28 inches vacuum, which would mean the removal of at least 90 per cent. of the air in the plant, attach a shipping tank of ammonia K to connection 5, and allow sufficient gas to enter to raise the pressure to atmosphere.

There is now 90 per cent. of ammonia gas mixed with 10 per cent. air. Close all connections, and pump the gas to pressure in the condenser and examine again for leaks.

If the work so far is found to be all right, open flange F, close cock M, and pump this mixture of gas and air to the atmosphere until there is 26 or 28 inches vacuum. This will leave 10 per cent. of the air and gas in the piping, but as 90 per cent. of this is ammonia, the charge would only have one per cent. of air.

Next permit the ammonia gas to flow in and fill the piping to atmosphere, which will force out what air remains in the compression chambers; then close up all pipe connections and the relief cock L, and start water over the condensing coils.

Start the gas pumps and permit the gas to enter from the shipping tank, and pass through the refrigerating coils to the pressure side of the machine until it obtains sufficient pressure to liquefy and deposit itself in the liquid tank C.

After a sufficient amount of gas is put to properly charge the plant, it is ready for refrigerating or ice-making.

CHAPTER VII.

CHARGING AND WORKING A CARBONIC ANHYDRIDE PLANT.

BEFORE CHARGING.

Fill the compressor with glycerine and run the machine for one or two hours with all the valves wide open.

CHARGING.

The steel flasks each contain about 40 pounds of CO_2. The number of flasks required will depend upon the size of the machine. Suspend the flask, valve upwards, from a spring balance and connect by a copper pipe to the evaporator. See that connecting joints are tight.

Note the weight.

Open the valve on the flask and on the evaporator. After the CO_2 has passed into the system, note the weight again. The difference is, of course, the weight of CO_2 that has passed into the machine.

After the flasks are half empty (not before), warm them with hot water. When empty, close the valve while the flask is still warm. If the flask still contains CO_2 it will remain cold at the lower end.

When first charging a new machine, blow the air out of the system by breaking the joint between the regulator and the pipe leading to it, the regulator being closed and all other valves opened, and blow two or three pounds of CO_2 through.

As the pressure, while charging, rises, carefully examine all joints. The slightest leaks become visible when the joints are painted over with soap and water as prepared for shaving.

GAUGES.

The CO_2 gauges on condenser and evaporator show on outer circle the pressure in atmospheres, and on the inner circle the corresponding temperature of CO_2.

WORKING CONDITIONS.

Having fully charged, start the machine with all valves open, and adjust the regulator (*i. e.*, the inlet valve of the evaporator), so that the condenser gauge will indicate on inner circle five degrees to ten degrees above the temperature of the cooling water at the inlet to the condenser, and the evaporator gauge ten degrees to fifteen degrees below the temperature of the brine or water to be cooled.

Under ordinary working conditions the compressor should be cold or partly covered with snow, and the delivery pipe from it should be rather warmer than the hand can comfortably bear. If the delivery pipe is not hot enough, slightly close the regulator, when the temperature will quickly rise. If compressor becomes warm, it points to regulator being insufficiently open.

If unable to obtain the conditions called for above, then the system is short of gas. As a further test of this, close the regulator. If the evaporator gauge falls rapidly and continuously, the system is short of gas. If sufficiently charged, this gauge should remain almost stationary for several revolutions of the machine. Moreover, if sufficient gas is present, the condenser gauge could hardly rise at all, even after working two minutes.

If short of gas, or in doubt, add more. Some extra gas in the system, up to a quarter charge, will do no harm. It will be indicated by condenser gauge showing 20 or more degrees above inlet water temperature. If machine is short of gas, the refrigerating work done will be but a fraction of its proper duty.

BRINE.

The temperature at which the brine is to be maintained

will depend upon the refrigeration that is to be performed. The density should be regulated by the addition of chloride of calcium until Twaddles' No. 2 densimeter shows 40 degrees, or till one gallon weighs 12.5 pounds.

COMPRESSOR PISTON.

The clearance spaces at the ends of the compressor being small, they must be maintained equal at both ends.

The piston is packed with hydraulic leathers, which will require examination and removal occasionally. It is very necessary that the nut securing these leathers should be well screwed up and locked. Where new leathers are put in, it is advisable, two days after starting, to tighten the nut up again.

VALVES.

The suction and delivery valves will also require occasional examination. When they require regrinding spare ones may be put in.

In the case of machines with the valve seatings making double joints, see that both copper rings are equally crushed by the valve casing. Leakage at the outer joint will indicate itself outside, but at the inner joint will not be perceptible except in reducing the work done by the machine.

TEST.

To test the work of the compressor, close the regulator, when the evaporator gauge should be pumped down from say 25 atmospheres to 5 atmospheres in about 200 revolutions. If slower, either the valves or the pistons are faulty.

GLAND.

This is packed with two hydraulic leathers, between which a pressure of glycerine is maintained by means of the special lubricator provided. The gland should not be screwed up too hard. The lubricator will require pumping up after some hours' work, and when the piston has moved four inches. This, however, should not occur under three hours if the

gland leathers and compressor rod are in good order. The lubricator valve should be opened a full term. The glycerine which leaks from gland should be caught, and, after filtering, used again. Great care should be taken to keep compressor rod free from scratches or marks, which would rapidly destroy the gland leathers.

If short of leathers, the gland may be temporarily packed with ordinary tallowed packing, thus: first put in two or three turns of packing, then the spiral ring, and then fill up with packing, care being taken that the ring comes opposite the glycerine outlet, when the gland is screwed up.

SEPARATOR.

Any glycerine passing into the compressor will be caught in the separator, and must be drawn off twice daily by slacking nut at bottom, and, after filtering, used over again.

GLYCERINE.

All glycerine should be free from water, acid and dirt.

STRAINER.

On suction side of compressor is a strainer, which should, with a new machine, be taken out and cleaned after the first and second day, and then occasionally.

STOPPING AND STARTING.

When stopped, it is not necessary to close any valves. The gauges will then equalize, standing at the pressure of the evaporator. Before starting care should be taken that the valves are open, but should this be neglected a safety-valve is provided to relieve pressure.

SPEED.

The speed, of course, varies according to the size of the machine.

LEAKAGE.

It is very necessary that all pipes, joints and glands of

spindle valves should be carefully examined and kept tight. For the first few days especially they should be examined daily, and all bolts and gland-nuts screwed hard up. The most minute leak must be instantly stopped.

TO EXAMINE COMPRESSOR.

Close the suction and delivery, screw down valves, and slack off a joint to let the gas escape. Make sure all pressure is gone before opening up.

EXTENDED SHUT-DOWN.

When the machine is to be stopped for a week or more the piston-rod should be withdrawn and carefully oiled or painted with tallow and white lead to avoid rusting.

STORES.

A supply of the following must be kept on hand:

- Flasks of CO_2.
- Glycerine.
- Chloride of calcium.
- Compressor piston leathers.
- Compressor gland leathers.
- Glycerine lubricator leathers, two sizes.
- Set of delivery valves (and seats, where loose).
- Set of suction valves (and seats, where loose).
- Compressor piston-rod, highly polished.
- Safety-valve discs.

CONCLUSION.

Details in the above would of course be varied in accordance with different conditions, those given applying in general to the Hall system.

CHAPTER VIII.

THE EFFECT OF CARBONIC ANHYDRIDE ON HUMAN HEALTH AND LIFE.

The use of carbonic anhydride as a refrigerating agent involves the consideration or the appreciation of the harmlessness of the effect of the same upon human health and life.

We must look to Europe for practical and scientific investigations along this line. From numerous experiments carried out by Dr. Marcet, and described in the Croonian lectures delivered by him before the Royal College of Physicians of London, he concludes that if after breathing an atmosphere heavily charged with CO_2, a person breathes fresh air, the blood quickly recovers its normal state of aëration, and gives out the whole of the CO_2 which is absorbed. He also quotes with approval Paul Pert's conclusions that when the atmosphere breathed is so heavily charged with CO_2 that death occurs, in such cases death is due to want of oxygen, and that the CO_2 is absolutely innocuous.

As to the proportion of this gas in the atmosphere which can be breathed with impunity, some experiments have been made by Dr. von Pettenkofer and Professor Emmerich, who, in company with others, shut themselves up in a small vault of the Institute of Hygiene at Munich with bottles of liquid CO_2, the contents sufficient to charge the atmosphere with 17 per cent. of CO_2. The vault was lit with candles. The gas was allowed to escape, and after eight minutes some difficulty in respiration was experienced; after 15 minutes some of the candles went out, and others were burning very faintly. By this time the bottles were empty. A sample of the atmosphere was then taken, and on analysis gave 8.54 per cent. of CO_2. One person remained in the vault for 25 minutes, and

on leaving he, as well as the rest of the party, in a few minutes entirely got over the effects of the experiment.

Rabbits have for over an hour withstood 34 per cent., and after being in an atmosphere containing even 60 per cent. for three-quarters of an hour, they have quickly recovered in the open air.

The fact that a flame is extinguished before the atmosphere becomes too bad to breathe is a safeguard of easy application.

The idea that any CO_2 escaping from a machine would, in virtue of its greater weight than the atmosphere, lie on the floor of the room, is erroneous, as, of course, the gas diffuses with the atmosphere, and this action is still further insured by the fact that any appreciable leakage will be at high velocity.

After these remarks it may be readily credited that it is common practice in the workshop after testing refrigerating apparatus using CO_2 to blow out the whole contents without the least inconvenience to the workmen.

CHAPTER IX.

THE THERMOPHONE.

An interesting as well as useful instrument, which among its various applications includes the field of refrigeration, is the thermophone. There is something fascinating about it to one who understands enough about electricity to grasp the ideas involved in the telephone, the Wheatstone bridge, and the change of resistance of an electrical conductor with a change in temperature. To one who does not comprehend these, the deeper the mystery, the greater the wonder and admiration. Just think of determining the temperature by the ear. What then is the thermophone? This much our Greek scholar could tell us, even though this might be the limit of his ability to help us out.

The thermophone is an electrical thermometer of the resistance type. It is especially valuable in determining the temperature of a distant or inaccessible place. It was devised for the purpose of obtaining the temperature of the water at different depths in a reservoir. It was so successful in operation that its inventors were encouraged to study further into the capabilities of the instrument with a view to adapting it to scientific and commercial work.

Many resistance methods for the determination of temperature have been used. All depend upon the principle that the resistance of a conductor to the electrical current varies with its temperature. It is readily seen that any apparatus capable of measuring the resistance of the material may also be used to measure its temperature, as one is the function of the other. In the instrument under consideration, advantage has been taken of the fact that different metals have different electrical temperature coefficients.

Two resistance or temperature coils of different metals, such

as copper and German silver, are placed side by side to be under the same conditions of temperature. The outer ends of these coils are connected by leading wires to the terminals of a slide wire where connections with a battery are made.

From the junction of the inner ends a third wire is carried to a movable contact on the slide wire. This third wire has in its circuit a galvanometer or a telephone used in connection with a current interrupter, operated by an independent battery supply, for the purpose of indicating the presence of a current. The whole is a form of the Wheatstone bridge, and the sliding contact is moved in the proper direction to balance the changing resistances of the bridge coils. For each degree of temperature there will be a different position of the slider, and by a proper calibration a graduated scale will be made. In practice the slide wire is wound around the periphery of a disc, the upper surface of which is graduated in degrees of temperature. The slide presses against the slide wire, and the movable index shows the temperature of the distant coils.

The temperature coils and third wire, properly insulated, are inclosed in a thin brass tube, strongly and hermetically sealed to withstand water-pressure or careless handling. The brass tube may be left straight or wound in a spiral as desired. The coils are made usually with leads nine feet long, but these leads may be connected with a triple cable of any length, so that they may be carried to any position desired.

It will be seen that the temperature of the leading wires will have no effect, as they are placed side by side and subject to the same changes, and one tends to influence the reading of the instrument in one direction as much as the other wire in the opposite direction. The temperature of the slide wire will have no effect upon the reading of the instrument, for being one piece of metal which has the same temperature throughout its length, each portion of it will rise or fall in resistance at the same rate with changes in temperature, consequently the ratio of its parts will not change.

The operation of taking a temperature-reading with the thermophone is as follows:

The coils are placed at the spot the temperature of which is desired, and the three leading wires are connected with the proper pole coils on the indicator box. The switch is turned to connect the battery, and the hand telephone is held to the ear. The index is moved back and forth over the dial. A buzzing sound will be heard in the telephone, increasing or diminishing as the index approaches or recedes from a certain section of the dial. A point will be found at which there is perfect silence in the telephone, and at that point the hand will indicate the temperature of the distant coils.

The coils must of course be located at the point whose temperature is to be determined. As the same is not the case in regard to the other parts of the apparatus, these may be located at any convenient point. There follows, in consequence, an interesting feature of the apparatus, namely: that by having any number of coils located at different points and a suitable switching device for switching the indicator to any of them as desired, one indicator only is needed. In short, the apparatus may be so installed that a man may, without leaving his office, find the temperature of any room of his factory or hotel or public building.

This interesting apparatus is not merely a laboratory toy or a novelty, but an instrument adapted to practical commercial purposes, and is a credit to the designers, Messrs. Warren and Whipple.

CHAPTER X.

WATER, ICE AND STEAM.

COMPOSITION.

Water is a liquid composed of hydrogen and oxygen in the proportion by weight of 88.9 parts of oxygen to 11.1 parts of hydrogen and in proportion by atoms in the molecule of two atoms of hydrogen to one of oxygen. The chemical symbol for water is H_2O.

COMBUSTION.

In ordinary combustion oxygen unites with carbon, forming carbon dioxide or CO_2. This combustion is accompanied by the giving out of heat. In the oxy-hydrogen blow-pipe, oxygen unites with hydrogen; the union being attended with a heat so intense as to be rivaled only by the heat of the electric arc. This heat is what is utilized in the calcium light.

The resulting product of this union, in which this intense heat is manifested, is water, the great enemy of fire.

BOILING AND FREEZING POINTS.

At an atmospheric pressure of about 14.7 pounds per square inch, corresponding to a height of the column of mercury in a barometer of about 30 inches, water freezes to ice at 32° F. and boils and is changed to steam at 212° F. The boiling point varies with the pressure. With an increase in pressure there is a higher boiling point.

The chemical composition of water is not changed by either freezing or boiling.

LATENT HEAT.

The latent heat of water is that heat that is required to change ice to water at the melting point, and to change water

to steam at the boiling point. This heat is not manifest by any change in temperature, and is accordingly called by various names, as latent, hidden, concealed, or inner heat. The values are respectively for liquefaction 142.4 heat units and for vaporization 966 heat units. The heat unit is the British Thermal Unit (B. T. U.), which is the quantity of heat required to raise one pound of water one degree Fahrenheit.

SPECIFIC GRAVITY.

Water is taken as a standard of specific gravity. Accordingly a value given for the specific gravity of a substance would mean the number of times that substance is heavier than an equal volume of water.

The value for the specific gravity of water, the standard, is of course unity or one. Accordingly a value for specific gravity less than one would signify that the substance was, according to common parlance, "lighter" than water and would accordingly float. A value for specific gravity greater than one would signify that the substance would sink in water.

To obtain the specific gravity of any substance the weights of equal volumes must be compared, *i. e.*, the weight of the substance must be divided by the weight of an equal volume of water.

Obtaining the specific gravity of a substance might be a most perplexing task but for a principle that is made use of in regard to the effect of submerging a body in a liquid upon its weight. It is found that the weight a body submerged in water (apparently) loses is equal to the weight of an equal volume of water. It will be noticed that this last is just what is wanted, in addition to the weight of the body itself, to obtain the specific gravity of the body. Accordingly an easy and accurate means is afforded of solving what might seem a serious and perplexing problem. The result is obtained, it will be noticed, without either knowing the volume of the body or actually weighing any water.

The statement in regard to water as the standard for specific gravity should be somewhat more precise. The standard is

pure distilled water at an atmospheric pressure of 14.7 pounds per square inch, corresponding to a height of the mercury column of the barometer of 30 inches, and at a temperature of 4° C. or 39.2° F. At this temperature water is at its greatest density. Above and below this temperature the specific gravity of water decreases.

While water is the general standard for specific gravity, the standard used for gases may be either hydrogen or air. Hydrogen is the lightest of the more common gases. Air is a mixture consisting of about four-fifths by weight of nitrogen (N) and one-fifth of oxygen (O). Hydrogen is about 14.5 times lighter than air and 11,160 times lighter than water.

SPECIFIC GRAVITY.

Standard	H.	N.	O.
Air	0.0692	0.972	1.1056
Hydrogen	1.0	14.0	16.0

At a temperature of 15° C. (59° F.) water is 819 times as heavy as air.

Using these figures for obtaining a ratio of the volume of water and that of constituent gases, we obtain a result as follows: If the weight of a given volume of water is 819, that of a corresponding volume of hydrogen is 0.0692, of oxygen 1.1056, of hydrogen and oxygen mixed in the proportions of these in water $\frac{0.0692 \times 2 + 1.1056}{3} = 0.4147$. Accordingly one volume of water would give $\frac{819}{0.4147} = 1977.3$ volumes of the constituent gases.

SPECIFIC HEAT.

Water is taken as a standard for specific heat. By specific heat of a body is meant the amount of heat required to raise the temperature of the body one degree, compared with the amount of heat required to raise an equal weight of water one degree. Water has the greatest specific heat of substances in common use. Strange to note, the gas hydrogen has a value

as high as 3.409, that of water taken as 1.0. The figures for specific heat will generally be less than 1.0.

The specific heat of ice is 0.5040, and of saturated steam about 0.4805, of air 0.23751, of oxygen 0.21751, and nitrogen 0.24380.

METRIC SYSTEM.

Water is taken as the connecting link in the metric system between measurements of volume and weight. The weight of one gram is taken as the weight of one cubic centimeter of water at 4° C.

MISCELLANEOUS.

Water is practically non-compressible.

Water is a poor conductor of heat. On this account, to heat water effectively advantage has to be taken of convection currents or circulation. These currents are due to the rise of water that has expanded and accordingly been reduced in specific gravity by heat, and the consequent fall of the colder and "heavier" water to replace the same.

Steam is invisible. A stream or jet of condensed steam may indicate the presence of steam. What is seen, however, is condensed steam, which is of course water.

Sea-water contains 3.6 per cent. by weight of solid matter in solution, the specific gravity being 1.029. The freezing-point of sea-water is 27° F., the ice being fresh. The boiling-point of sea-water is 213.4° F.

The expansive force of freezing water is simply irresistible, amounting to possibly 2,000,000 pounds per square inch.

CHAPTER XI.

LIQUID AIR.

The practical relation between the subject of liquid air and refrigeration is yet to be demonstrated. While liquid air is looking around for spheres of usefulness and possibilities before it that are as yet undeveloped, it would be well for the enthusiast on the subject of mechanical refrigeration to bear in mind that it is to work of a similar character and with similar indefiniteness as to purpose and destiny that mechanical refrigeration owes its existence. Accordingly, there is a kindred relation between the two. The history of the liquefaction of air and of gases in general is extended as to time and includes a long list of experimenters. A few of the typical methods of operation and the principles involved may be worthy of consideration.

CRITICAL TEMPERATURE AND PRESSURE.

In general, we may say that to liquefy a gas it must be reduced in temperature and subjected to pressure. To be more definite, we may say that to reduce a gas to a liquid at any given pressure, the gas must be reduced in temperature below a certain point. To emphasize the importance of this latter statement, it should be understood that at any temperature above the particular point a pressure sufficient to increase the density of the gas to an amount even greater than that of the liquid obtained by liquefaction, will not reduce it to the liquid state. There is, accordingly, a point in temperature called the critical temperature, to which gas must be reduced before it can be liquefied even with exceedingly great pressure. The pressure required to reduce the gas to a liquid at the critical temperature is called the critical pressure.

A reduction in the pressure results in a further reduction of the temperature of liquefaction.

REDUCTION OF TEMPERATURE.

Practically the first step in the direction of obtaining a reduction in temperature, strange to say, is to obtain an increase in temperature. For instance, we may start with a gas at the normal temperature. Compress this gas. The result will be a rise in temperature of the gas. As the gas is compressed a certain amount of work is exerted on the gas which must manifest itself in some way. The energy thus expended appears in the form of heat.

Now if the matter of reversing of these conditions is considered, what do we find to be the result? In this case the gas is allowed to expand, performing work. This work is the result of the expenditure of heat energy originally contained in the gas. In giving up this heat the gas is reduced in temperature.

In case there were no loss of heat in the two operations mentioned and no incidental losses the final result would be the restoration of the original work expended and the return to the original temperature and pressure of the gas. In case, however, during the first operation, the so-called heat of compression is removed, the result of the second operation will be a reduction in temperature below the original.

Here we have in consequence a means of reducing temperature. This consists briefly in subjecting a gas to pressure, cooling it, and allowing it to expand. In this case the reduction in temperature is due to work performed by the expanding gas, which is the principle involved in the operation of the compressed air refrigerating system.

If the combination of pressure and cooling is sufficient in the case of a particular medium to produce liquefaction of the same, the reduction in temperature upon release of pressure may primarily result from the absorption by the medium of the latent heat of evaporation, as is the case in the systems of refrigeration utilizing ammonia, sulphur-dioxide and carbon-dioxide.

The use of freezing mixtures of salt and ice is well known. These are of course not to be considered directly in obtaining exceedingly low temperatures. They may, however, be utilized as auxiliary in bringing down the temperature of the medium conveyed in cooling coils.

In this connection it is interesting to note that it is told that the temperature obtained by Fahrenheit with a mixture of salt and ice he called zero of his thermometer scale under the impression that this was the lowest temperature obtainable.

PRESSURE.

In these days of highly developed pumps, we may wonder at the method once adopted, as, for instance, by such men as Faraday, to obtain high pressures for experimental purposes. This method involved the use of chemical action. That we have not entirely abandoned this method is shown by methods employed in gunnery. We have the case of the pneumatic guns on the *Vesuvius* as a modern example of the pressure due to chemical action being replaced by pressure obtained by pressure pumps. It must be acknowledged in this connection that the substitution was not made on account of superiority of the pressure obtained.

METHODS OF LIQUEFACTION OF GASES.

FARADAY'S METHOD.

In 1823 Faraday succeeded in liquefying the gas chlorin. His apparatus consisted of a bent U-shaped tube, closed at the ends, an alcohol lamp, a vessel with freezing mixture, chemicals for producing pressure, and the chlorin gas.

In use the U-shaped tube was inverted, the arms projecting downward. In one arm was the chemical which produced pressure when heated by the flame of the alcohol lamp. The end of the tube away from the alcohol lamp was kept in a freezing mixture.

The result was that the gas was compressed by the pressure produced, and cooled by the freezing mixture.

This compressed and cooled gas was released. The portion that evaporated abstracted heat from the remainder.

As stated above, by such a primitive method as this, Faraday succeeded in liquefying chlorin.

THE SERIES METHOD.

The series method involves the use of two or more gases in series to act upon the gas to be tested. The gases used are, of course, especially selected with reference to their points of liquefaction. The one with the highest point of liquefaction acts upon the next in order, and so continued until finally the liquid to be tested is acted upon.

The description given below is merely given as typical of this method. Different gases than those mentioned may, of course, be used, and various arrangements of details may be followed.

As stated above, the process consists in obtaining liquefied gas by a series of compression pumps and different gases in separate and distinct processes.

This process might be named the extracting of latent heat process, for in it we have no less than four different stages, as follows:

First, carbonic acid gas.

Second, ethylene gas.

Third, oxygen gas.

Fourth, liquefied air.

The severe work necessary to be done in order to obtain liquefied air is without question due to the imperfect chemical affinity in its make-up, and that the different parts having the same weight intermingle in the atmosphere at large without combining.

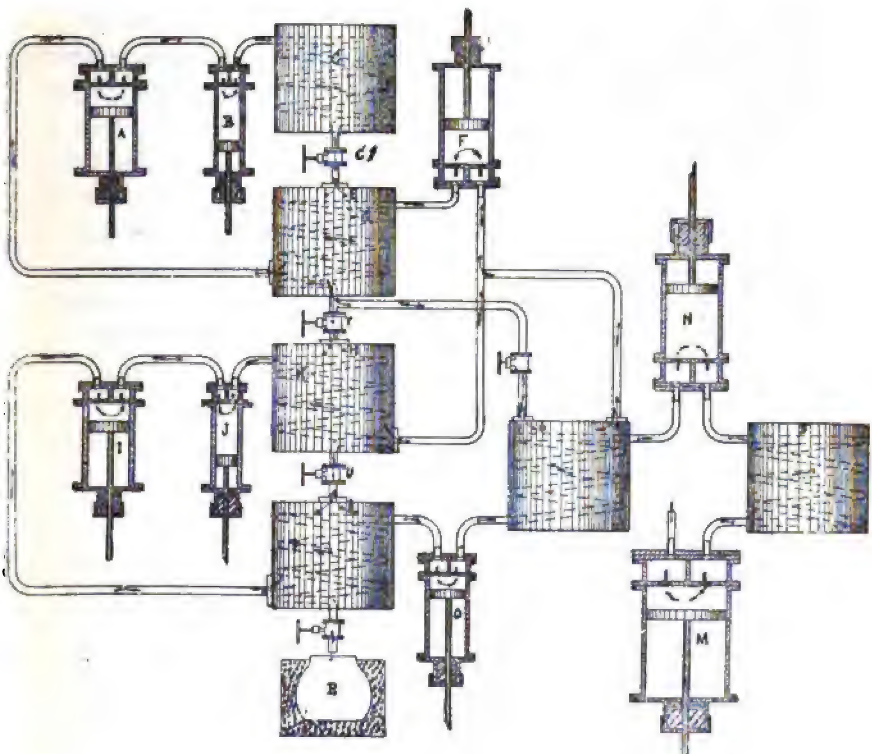
Perhaps this can be better understood by noting the action in breathing; in taking a long breath and then expelling the air from the lungs, we find by noting carefully that the muscular effort in expelling the air is much less than that used in inhaling it.

This, in a measure, is because the lungs have taken out the

oxygen, leaving the nitrogen, etc., to be thrown off, the oxygen having been retained in the blood circulation.

This fact would indicate that the molecules of the different gases remain distinct at atmospheric pressure, awaiting some law of nature to form a combination of affinity which often comes by heat change.

FIG. 201.



THE SERIES METHOD OF LIQUEFYING AIR.

The following gives the method of operation: See Fig. 201.

"A" and "B" = compound compression pumps used in placing a pressure on carbonic acid gas.

"C" = condenser coils placed in tanks surrounded by acid and salt or cold water.

2 = condenser tank.

"Cl" = expanding cock to permit the liquefied carbonic gas to expand in a cooling chamber.

"E" = expanding chamber for carbonic acid gas which is expanded in the tank at one atmosphere, 14.7 pounds absolute, or below, and returns to suction side of carbonic acid gas pumps "A" and "B."

"F" = ethylene for creating a liquefying pressure in the condensing coils.

"G" = condensing coils for condensing ethylene gas, which is cooled by being bathed in vaporizing liquid of carbonic acid gas in tanks.

"H" = tank for evaporizing the ethylene gas, being liberated at the expanding cock, "T" (from this tank the vaporized ethylene gas returns to the gas pump "F" for re-liquefaction).

"I" and "J" are compound gas pumps for liquefying oxygen gas, this being pumped into coil "K," which is bathed in ethylene vaporizing gas at a temperature of 345° below zero, it being sufficient to liquefy the oxygen gas in the coils.

The oxygen gas in the liquefied condition is permitted to expand at cock "U" into cylinder "L," where it is maintained at one atmosphere absolute, the temperature here being 360° below zero Fahrenheit.

"M," "N" and "O" are cylinders composing a compression air pump, having the ability of compressing to 100 atmospheres or about 1,500 pounds per square inch.

In passing from the first cylinder "M" to cylinder "N," the air is passed through a cooling coil, surrounded by salt and ice.

From the cylinder "N" the air passes to cylinder "O." Between the cylinders the air again passed through a coil submerged in liquefied ethylene gas.

From cylinder "O" the air passes into a coil "P" surrounded by liquefied oxygen gas which is being vaporized. In this coil, under the intense pressure of 100 atmospheres, and at a temperature of 460° below zero, liquefied air is ob-

tained. This liquid air is allowed to flow into an open receptacle "R." When the first liquid flows in, it immediately vaporizes and carries off the surrounding heat until the entire vessel is at a temperature of the liquefied air, viz., 460° below zero, thus becoming a vapor only as it receives heat from the surrounding atmosphere.

METHOD OF TO-DAY.

The method of Faraday is crude and even dangerous. The series method is complex and expensive. A method to be successful and practical at least in the commercial sphere must be simple and efficient. It is one thing to be successful in the laboratory and quite another to be successful in the sphere of commerce.

Again we have the difference between mechanical efficiency and commercial efficiency. While the process may be quite efficient, the materials used may be so expensive as to render their use on a large scale prohibitive.

It is pleasing to note that notwithstanding the exacting demands indicated it would seem as if they had been quite effectively met. What could be more desired in the way of simplicity as to medium for liquefying air than simply air itself? As has been stated, the idea involved in general of obtaining low temperature has been to permit a gas under heavy pressure to expand. As stated likewise in regard to carbon dioxide, this gas is comparatively easily obtained in the solid form by exposing a quantity of liquid carbon dioxide to evaporation. The processes involved are those heretofore mentioned of compression, cooling and expansion.

There are several different successful methods of liquefying air that use only air as the medium. All of these depend upon the cooling effect realized in the expansion of air in the final stages of the process. Air reduced in temperature by this expansion process is utilized to cool the air supply in the conveying pipes. By maintaining this process, the temperature of the air in the conveying pipes and that of the expanded air are continually reduced by what is called the re-

generative process until the temperature of liquefaction is finally attained.

Radically different methods of realizing the cooling effect due to the expansion of the compressed air are employed, one method involving the use of expansion cylinders and the other allowing the air to expand in suitable chambers, without such cylinders. The principle involved in either case would seem to be the same, although elaborate arguments have been set forth to explain that expansion in the latter case is accompanied by a drop in temperature. The difficulty seems to be involved in Joule's law which states that when a gas is allowed to expand without doing work its temperature remains constant. In the light of present knowledge it is difficult to conceive of a gas expanding without doing work, although this work may be upon itself. As in the processes under consideration the expanding air has the pressure of the atmosphere to contend with it would seem as if it clearly had work to do. Then there is also the effect of wire-drawing through an expansion valve at the point where the air is released from the conveying pipe, which results in drop in pressure and temperature.

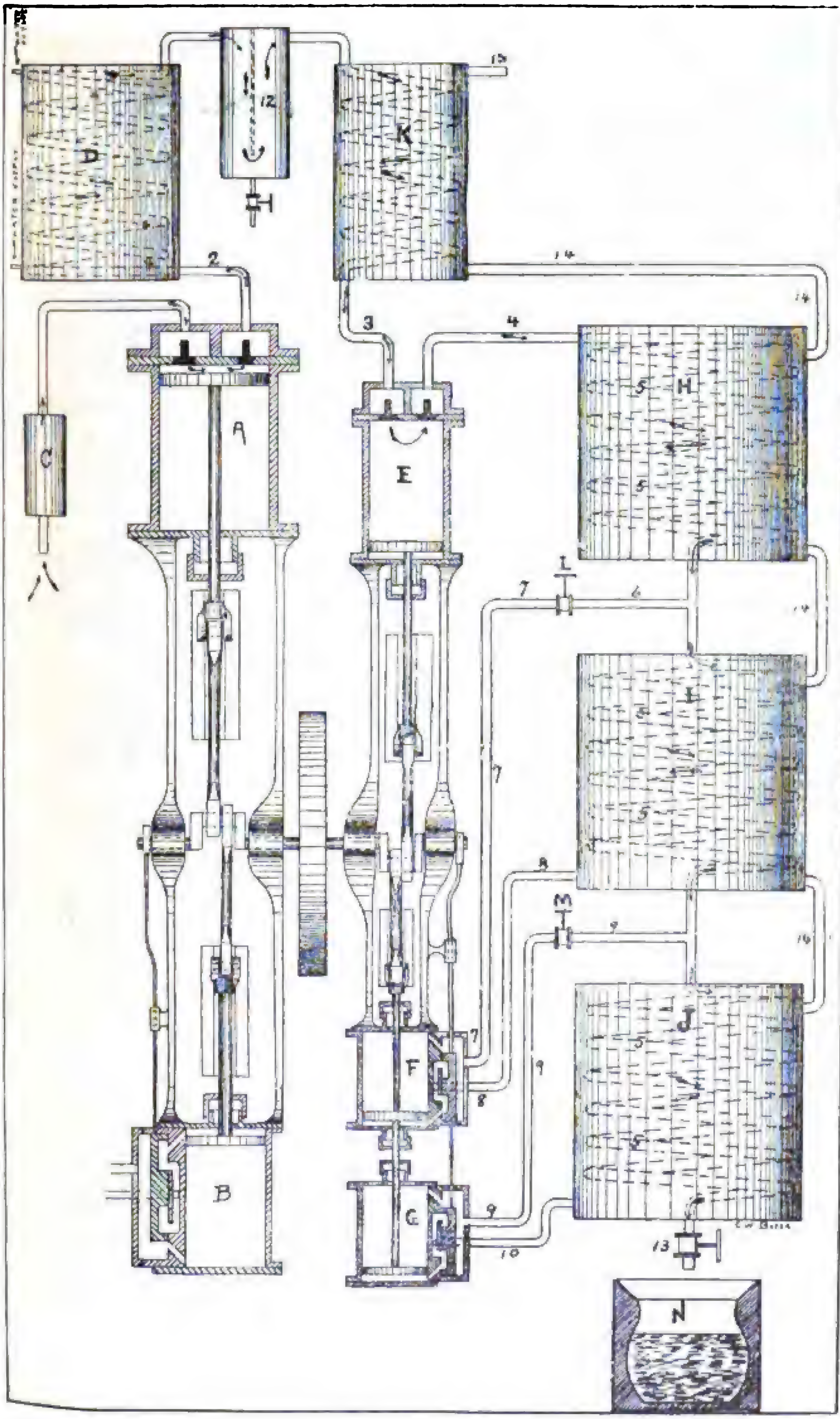
Among those who have been particularly successful in the development of the two different methods mentioned are Professor Linde, who has employed expansion cylinders and Mr. Charles E. Tripler, who employs regenerative expansion chambers. Below will be found an outline of Professor Linde's process and a thermodynamic explanation of the regenerative process taken in part from Reeve's "Thermodynamics."

PROF. LINDE'S PROCESS. *

The Linde process of liquefying air is one in which is used a system of compression and expansion cylinders, following the well-known principle that if compressed air is allowed to expand in a cylinder, we have the result of heat units consumed and energy produced. This can be measured by the

*F. H. Boyer in The Engineers' Magazine.

Fig. 202.



LINDE METHOD OF LIQUEFYING AIR. (Page 413.)

Joule rule of effort and result. This process may perhaps be better understood by referring to Fig. 202.

A. First air compressing cylinder.

B. Steam cylinder.

C. Water interceptor.

D. First air compressing cooling coil.

E. Second air compressing cylinder.

F. First air expanding cylinder.

G. Second air expanding cylinder.

H. First condensing chamber.

I. Second expanding chamber.

J. Third condensing chamber.

K. Second compressor cooling coil.

L. Stop valve from condensing coil to air expanding cylinder.

M. Stop valve from condensing coil to second air expanding cylinder.

N. Flask for securing liquid air.

2. Pipe connection from first compressor to cooling coil.

3. Pipe connection from second cooling coil to second compressor.

4. Discharge pipe from second compressor to condenser.

5. Condensing coils.

6. Connection between condensing coil and first air expanding cylinder.

7. Supply connection to air expanding cylinder.

8. Exhaust pipe from expanding cylinder F to cooler I.

9. Air supply pipe to expanding cylinder G.

10. Exhaust pipe from expanding cylinder G to cooling chamber J.

12. Water interceptor.

13. Final pipe and valve on bottom of liquid receiver.

14. Connections between cooling chambers to allow the cool air to pass to a higher cylinder.

15. Final exhaust connection allowing expanded air to return to the atmosphere.

The air is admitted through the water interceptor C, where

by a chemical process about 90 per cent. of the water is removed.

The air next passes to the air compressor or pump A, where it is compressed to 1000 pounds pressure per square inch. This compressor is surrounded by a water jacket to remove the heat of compression.

In the next process the air entering the air cooler D passes through discharge pipe 2. There should be several of these coils cooled with running water until the air is brought to the normal temperature of the water.

In the second cooling tank, K, we have a refrigerant of expanded air, a continuation of the discharge from cylinder H, using the cylinder encasing coil K as a cooling chamber.

An interceptor, 12, is used to remove the remaining 10 per cent. of water necessary to insure the constant operation of the apparatus.

From coil K the air at 1000 pounds pressure and at a temperature of 62 degrees Fahr. below the freezing point of water passes to the second compressor, E, where it is pumped up to 3000 pounds per square inch and enters the continuous coil, 5. This pressure is maintained constant on the entire coil, being liberated only at valves L, M and 13.

Tanks H, I and J are condensing tanks made to hold air at the normal pressure of the atmosphere and must be insulated in the best manner known.

Expanding cylinder F, in use, relatively speaking, is similar to a steam engine cylinder excepting that it uses air at 3000 pounds per square inch as a motive power. This air is taken from the condensing coil through pipe 7, and liberated by valve L.

These air-expanding cylinders must be constructed with an adjustable cut-off and so made that the energy developed may be consumed in the compressing cylinder to aid in compressing the air. These may be connected up in tandem or by belt connection to a shaft driving for power.

The initial pressure entering cylinders F and G being 3000 pounds per square inch, the final must be near the atmospheric

pressure, and when working under these conditions the exhaust passing from the expanding chamber F would be 184 degrees Fahr. below the freezing-point of water.

The air at that very low temperature enters the cooling chamber I which contains a second section of coil 5, holding the air at 3000 pounds per square inch, and reduces the temperature of the compressed air to that of the expanded air, or 184 degrees Fahr. below freezing.

The second expanding cylinder, G, takes its supply from the condensing coil at a point below the tank I. This supply passes through pipe 9 to the cylinder and works under similar conditions as described for cylinder F. The exhaust from expanding cylinder G passes through tank J and surrounds the last series of condensing coil 5, bathing it in a temperature of 411 degrees Fahr. below the freezing-point of water.

In doing work of this character, the feature of induction of heat by radiation is very large and often enters to a degree which interferes in obtaining the result desired.

In liquefying air we require a static condition of 383 degrees below the freezing-point of water when exposed to a normal pressure of the atmosphere.

Air under pressure of 3000 pounds per square inch and held in a static condition would become a liquid at 280 degrees below the freezing-point of water.

As the liquid air collects in the bottom of the condensing coil it is allowed by a valve, 13, to flow into an open flask, N. The first liquid air falling into the flask vaporizes, carrying off the heat until it has cooled the flask to its normal temperature, or 383 degrees below freezing, when the air remains liquid and only becomes a vapor as it takes up heat by conduction.

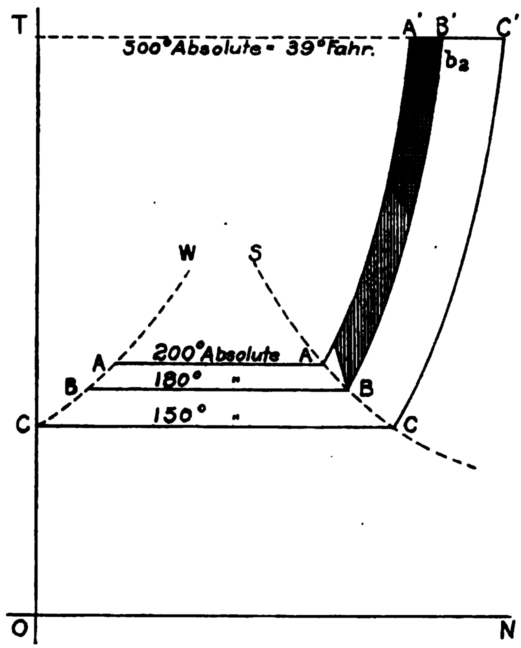
In shipping liquid air, an open vessel is used. This prevents the heat which is taken up by boiling an intensely volatile substance from creating an intense pressure.

REGENERATIVE PROCESS.

In Fig. 203 let the curves W and S represent the entropy-

temperature relations of liquid air and saturated vapor of air respectively. Since the critical temperatures of oxygen and nitrogen are —181° and —231° F. respectively, or 280 and 230 degrees absolute Fahrenheit respectively, the entire diagram must be imagined as lying below these very low temperatures. The boiling-points under atmospheric pressure of oxygen and nitrogen are 165° and 144° F. absolute respec-

FIG. 203.



ENTROPY-TEMPERATURE DIAGRAM FOR REGENERATIVE PROCESS OF AIR LIQUEFACTION.

tively. Let CCC′ be the constant-pressure curve at atmospheric pressure. Let AA and BB be two isothermals of vaporization at pressures considerably above atmospheric; in practice they are commonly 30 and 10 atmospheres respectively. Let AA′ and BB′ be isomorphs of superheated air-vapor at these same pressures respectively. The ordinary thermal condition of atmospheric air would then be represented by some such point as C′.

In Fig. 204 let C be the diagram of an air-compressor taking in atmospheric air and compressing it, as nearly isothermally as possible, to the pressure of BBB′, Fig. 203, and discharging it into the reservoir B, Fig. 204. Let A be another compressor taking its supply of air from B and discharging it into the conduit *aaa* at the pressure of AAA′, Fig. 203. This high pressure conduit *aaa* passes into the interior of the pipe *bbb*.

FIG. 204.

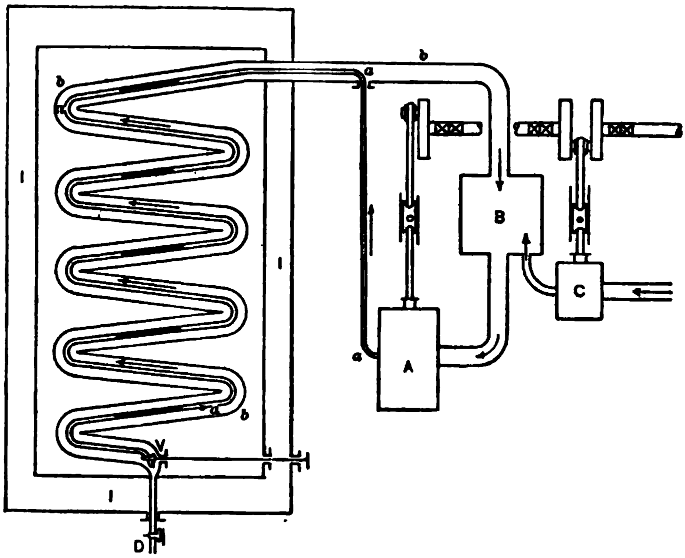


DIAGRAM OF AIR LIQUEFACTION APPARATUS—REGENERATIVE PROCESS.

The two together are formed into a coil presenting a large amount of surface and leading to an end at V. The coil is encased on all sides with thermal insulation III, which is constructed with great care. At the terminus of the pipe *aaa* is a valve V opening into the larger medium-pressure pipe *bbb* and fitted to be adjusted by hand from without. From the terminus of *bbb* is a drain-line passing downwardly through the insulation and ending in a drain-cock D.

The thermal activity of the apparatus illustrated in Fig. 204 may be now traced by means of Fig. 203.

The compressor C supplies air at atmospheric temperature to the reservoir B at the same temperature. The compressor A supplies air to the pipe *aaa* at the higher pressure AAA′, but still at atmospheric temperature; for temperatures may be supposedly kept down to atmospheric by cold-water jackets. This double process may be shown in Fig. 203 by the line C′B′A′, of isothermal compression (although properly at a higher level than drawn). The highly compressed air then traverses the pipe *aaa* and arrives at the valve E in the condition A′, Fig. 203. It finds the valve V slightly open and is wire-drawn through it into *bbb*, its pressure falling to BBB′ and its temperature to b_2 Fig. 203, by passage down the constant-heat curve $A'b_2$, the cycle being represented by the triangular figure, with black shading, shown in Fig. 203.

In traversing the pipe *bbb*, Fig. 204, this current of air reduces the temperature of the A-pressure air coming in along *aaa* so that the same arrives at V at this lower temperature, corresponding to b_2, Fig. 203. Further reduction in temperature results from wire-drawing through V, the cycle assuming a quadrilateral form. As the process is continued, the cycle deepens along the isomorphs, as represented by the figure with horizontal section lines, Fig. 203, which corresponds to one of the intermediate stages, until the point of liquefaction is reached at B, the cycle for this feature being represented in the figure with vertical shading.

Lord Kelvin's formula for the drop in temperature D involved in each of these passages across from the AA′ isomorph to the BB′-isomorph is

$$D = 0.497\,(P_A - P_B)\left(\frac{493}{T}\right)^2$$

wherein the pressures are measured in atmospheres and the temperatures in degrees Fahrenheit. T is the initial absolute temperature at the departure from the upper pressure.

So the process goes on, all temperatures within III falling steadily meanwhile, until finally the steady fall of the point successively represented by b_2 results in its coincidence with B. As the processes which resulted in temperature-fall due

to abstraction of heat still continue, their further action must result in the condensation of some of the air of BB-pressure. This condensation drains to the valve D, and may be there drawn off into an external vessel.

It will be obvious, from a sight consideration of the geometrical laws controlling the curves SB and *ab*, that at these very low temperatures they must be much nearer to parallelism than is the case at ordinary steam-temperatures. How nearly they approach parallelism, whether *a* reaches A before *b* reaches B, or the opposite, cannot be said. If *a* does reach A before *b* reaches B, it must indicate that liquid is first formed in the pipe *aaa*, just as the moisture in a throttling-calorimeter is evaporated by a similar process. But whether this be the case or not does not affect the thermodynamic explanation of the final result.

It may be well to state right here that Fig. 203 is modified from the one used in Reeve's "Thermodynamics" in accordance with suggestions from Prof. Reeve, as the original diagram, though correct, was somewhat misleading in not clearly bringing out the quadrilateral feature of the cycle in the lower stages.

THE FUTURE.

The utility of liquid air and its sphere of usefulness are at present merely matters of speculation. Sufficient has, however, been shown by results already attained to indicate that there is much to be looked for along the line of the unexpected.

For instance, who would have anticipated that liquid air or oxygen would be used for blasting purposes? Nevertheless, this has proved to be one of the first practical uses to which it has been applied. A fractional distillation will enable the nitrogen, which evaporates at a temperature 13° higher than oxygen, to be driven off, giving a liquid of greater efficiency than liquid air. A little cotton with charcoal dust soaked in this liquid oxygen, and set off by a spark, will explode with tremendous force. A safety feature is the fact that in case of

failure to explode the oxygen evaporates, obviating all further danger of explosion.

The liquid air when confined is liable to cause an explosion, due to its tendency to expand. The increase in volume of the liquid air as it assumes the form of gas, is to about seven hundred and fifty times the original volume. Accordingly it should not be kept confined. We hear more or less about shipping liquid air in open cans, and pouring it in open air like water. If the attempt were made to ship liquid air in closed cans, some one would probably hear it when it went off, but it would not be likely to reach its destination. So far as pouring it about like water, or like milk, there is a difference which tends to make the pouring of liquid air a comparatively expensive process. When the milkman pours the milk from the measure into the pan, most of the milk in the measure passes from the measure to the pan. Practically that which fails to reach the pan is still adhering to the sides of the measure. It may be said that whatever fails to reach the pan is still in the measure. With liquid air the case is different. As in the case of the milk, some will fail to reach the receiving vessel in the attempts to pour it from one vessel to another. The difference lies in the fact that instead of clinging to the sides of the vessel, the missing liquid will have evaporated.

The reason that the unexpected is to be looked for among the developments of liquid air may be safely assumed from some of the unexpected results that have been already attained. It is true that the substance air itself has in most cases little to do with the results, as they are to be attributed for the most part to the effects of intense cold, so that instead of speaking of the results attained by liquid air, we should more generally speak of results attained by intense cold or perhaps preferably of a low degree of temperature.

Here are some of the facts that suggest hidden mysteries of the future. Most of the facts enumerated below were mentioned in the excellent article on "Absolute Zero," by William Clark Peckham, in the Century Magazine.

Iron and steel become as brittle as glass. Gold, silver, plati-

num, copper and aluminum are not so affected. Lead becomes stiff and elastic like steel. The tensile strength of metals is increased.

Rubber cooled is rendered rigid and fragile, while leather remains flexible.

Ivory, cooled to the temperature of liquid air, held in a strong light, is seen in the dark to glow with a brilliant phosphorescence. Tungstate of calcium, which is strongly phosphorescent in Röntgen rays, loses that property at the temperature of liquid air.

The effects upon chemical affinity are equally remarkable. The indications are that all chemical action ceases at absolute zero. Sodium, cooled in liquid air, will not take fire in water till it is warmed again. Fluorin is the most intensely active of the elements. It combines rapidly with other elements, excepting oxygen, gold and platinum, and explosively with many. It burns flint with a brilliant glow, and charcoal and silicon with fiery scintillations. Iron exposed to it is heated to an intense white heat. But Professors Dewar and Moisson liquefied fluorin at about 336°, and lo! it was shorn of all its strength. It retained its activity for compounds of hydrogen only, and hydrogen has a lower boiling-point than fluorin.

The change in electrical properties is none the less marked. A large number of tests made by Dewar and Fleming show that at absolute zero all pure metals would cease to offer resistance to the electrical current. Perhaps electrical waves traverse external space without loss of energy.

With these facts before us, who can but say that the future will yet reveal unexpected and hidden possibilities?

RECENT RECORD.

In looking over the record of liquid air for the last few years we find much to substantiate our statement made in our previous issue, to the effect that we must look to the future to "reveal unexpected and hidden possibilities." We fail to find evidence of liquid air being utilized as an agent in the production of power, to drive out cars, automobiles or steamships, or to operate electric generators, or in the field of refrigeration.

In the field of scientific research, however, we find that liquid air, or other gases liquefied at low temperatures, as oxygen and hydrogen, have been of conspicuous and valuable service. As we have previously stated, most of the results attained are due not particularly to the effects produced by the gases involved, but rather to the effects of temperature.

One particularly fascinating phase of this subject is treated in an interesting article by Allan MacFadyen, M. D., M. B., Ch. M., on "The Effects of Low Temperatures upon Organic Life," from which we present a few extracts.*

"The experiments about to be referred to extended over a considerable period of time. The forms selected for the test were certain species of bacteria.

"The ideal test reagent appeared to be liquid air, as with its aid it was possible to reduce the temperature to about 190° C. below freezing point. A typical series of bacteria was employed, possessing varying degrees of resistance to external agents. The bacteria were first simultaneously exposed to the temperature of liquid air (about 190° C.) for twenty hours. In no instance could any impairment of the vitality of the organisms be detected as regards their growth or functional activities. This was strikingly illustrated in the case of the phosphorescent organisms tested. The bacterial cells in question emit light, which is apparently produced by a chemical process of intracellular oxidation, and the luminosity ceases with the cessation of their activity. The organisms when cooled down in liquid air become non-luminous, but on rethawing, the luminosity returned with unimpaired vigor as the cells renewed their activity.

"Professor Dewar kindly afforded the opportunity of submitting the organisms to a still more severe test, viz., an exposure to the temperature of liquid hydrogen, about —250° C. The same series of organisms were employed and immersed at this temperature for ten hours, and again with no appreciable effect on the vitality of micro-organisms.

* From Harper's Magazine, Copyright, 1903, by Harper & Brothers.

"The experiments could not be regarded as complete without an attempt being made to answer the question, Will organic life succumb eventually under the prolonged action of such low temperatures? The organisms were accordingly immersed directly in liquid air and kept at a temperature of about —190°C. for a period of six months. The vitality of the organisms even under these conditions remained unimpaired. One of the main effects of such prolonged exposure to the temperature of liquid air would be, if one may so express it, a chemical anæsthesia of the cells in question as regards their internal and external economy. The ordinary manifestations of life cease at zero, but at the temperature of liquid air and with such prolonged exposure, it is feasable to assume that the intracellular activities on which these depend likewise cease, inasmuch as the two cardinal conditions of active cell life are withdrawn, viz., heat and moisture.

"It is difficult to form a conception of living matter under this novel condition which is neither life nor death, or to select a term which will adequately describe it. It represents living matter in a new and hitherto unobtained "third" condition, and constitutes perhaps the most perfect realization of the state of suspended animation.

"It could hardly have been surmised that the discovery of liquid air would find such immediate application in biological research, and supply the ideal method of testing the influence of low temperatures on organic life. Nor does this exhaust the possible applications of freezing methods to biological inquiry. Experiments recently made have shown that the physical properties of bacterial cells become greatly altered at low temperatures. The typhoid bacillus, for example, becomes so brittle at the temperature of liquid air that its mechanical trituration is a comparatively easy matter. The cell juices of the typhoid organism have been obtained in this manner, and their direct study rendered possible. The ultimate problems of life are cellular problems. There can be little doubt, therefore, that the freezing and cold grinding methods have opened out one of the most promising fields of research with regard to the intimate physiology of the cell.

"A considerable amount of speculative interest attaches to the results that have so far been obtained. The origin of life remains the inscrutable problem which, if it continues to baffle, will ever continue to attract human intelligence. All the theories and all the deductions that have hitherto been put forward may be summarized in one interrogative sentence: Did life *arise* or did it *arrive* on the surface of the earth? If life was of purely terrestrial origin, the theory of its spontaneous generation would furnish the easiest solution, but unfortunately experimental inquiry has negatived such an attractive explanation.

"There remains the possible evolution of organic out of inorganic matter. The beginnings of life might possibly be sought for amongst the inorganic constituents of the earth.

"This theory, although it is beyond reproach from an evolutionary point of view, is lacking on any trustworthy experimental basis, whilst recent inquiry upon organic life tends rather to widen than to narrow the gap that exists between living and dead matter. The alternative hypothesis is that life was transferred to the earth, as it might be to any other world, as soon as the suitable physical conditions arose. The earth, according to this hypothesis, was 'infected' with the germs of life. The extraterrestrial theory of the origin of life has been particularly favored by the physicists, and notably by Professor Helmholtz and Lord Kelvin. We know that cosmic dust from distant worlds is constantly falling upon the surface of the earth, and that meteorites are continually colliding with its atmosphere. As Helmholtz remarks: 'Who knows whether these bodies, which everywhere swarm through space, do not scatter germs of life wherever there is a new world capable of giving a dwelling-place to organic bodies?'

"It has been proved that bacterial cells can grow and multiply at the abnormally high temperature of 72° C.; that they can be exposed unscathed to a temperature as low as —190° C. for six months, and that they have even survived a temperature which is only 22° above the absolute zero. These results profoundly modify our conceptions as to the

temperature conditions under which it is possible for organic life to exist. The results might even be cited in favor of the cosmic theory of the origin of life on the earth."

Thus we find liquid air serving as a reagent in problems bearing upon the modest field of research involving the determination of the origin of life upon the earth, leaving the moré mysterious problem of the ultimate origin of life, as of yore, in the hands of science, philosophy and theology.

INDEX.

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